MEASUREMENT OF VOLATILE ORGANIC VAPORS IN SOILS AS A TECHNIQUE FOR CHARACTERIZING GASOLINE CONTAMINATION IN GROUND WATER AT A BULK FUEL LOADING FACILITY; INCLUDING AN ANALYSIS OF THE EFFECTS OF ENVIRONMENTAL VARIABLES

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MEASUREMENT OF VOLATILE ORGANIC VAPORS IN SOILS AS A TECHNIQUE FOR CHARACTERIZING GASOLINE CONTAMINATION IN GROUND WATER AT A BULK FUEL LOADING FACILITY; INCLUDING AN ANALYSIS OF THE EFFECTS OF ENVIRONMENTAL VARIABLES

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CHAPTER I

INTRODUCTION

Soil Organic Vapor Measurement in Environmental Assessment Studies

Soil vapor sampling is becoming increasingly important as a remote sensing method in ground water contamination investigations, serving mostly as a preliminary indicator of the horizontal extent of volatile hydrocarbon contamination in ground water. The value of soil vapor sampling lies in its relative speed and low expense as compared to other investigative methods. A soil vapor survey can provide fairly dense and detailed information on subsurface volatile hydrocarbon contamination over a very wide area in a short time, and at less cost than any other equivalent method of subsurface investigation. A strong correlation between volatile organic compounds (VOC's) in soil gas and VOC's in ground water has been demonstrated (Marks, et al, 1989). Soil vapor surveys are also of relatively low impact, both to the natural environment and to site activities (Tillman, 1989, I).

It has been demonstrated that volatile compounds are present in most if not all, Superfund sites (Plumb, 1985), and there are known to be a large number of leaking

underground storage tanks and pipelines in the United States. Soil vapor sampling may be used at many of these sites to quickly and inexpensively provide an initial assessment of the extent of soil or ground water contamination. This information may then be used to decide placement of monitor wells or soil sampling locations. In order to apply soil vapor sampling most effectively, however, thorough understanding is required of the factors which affect the movement of hydrocarbon vapors through the geologic media. This paper reviews these factors to provide the necessary background for further examination of the topic.

Objectives and Scope of Study

A variety of techniques have been used by others to obtain and analyze soil vapor samples at sites of suspected ground water impact. This thesis study examines several methods in application at a bulk fuel loading facility where a pipeline leak has allowed liquid hydrocarbon (gasoline) to impact the ground water. The objectives of this study are: to examine different soil vapor sampling techniques and attempt to define those most effective in particular applications; to apply these techniques in an attempt to characterize the volatile organic ground water contamination at the site; and to define and attempt to isolate the effects of environmental variables on the collection, analysis and interpretation of soil vapor

samples as measured in the field (ie: under natural, in contrast to laboratory conditions). Another objective of the study was to examine and develop practical quality assurance - quality control methods for general usage in soil vapor measurement studies.

Hydrocarbons were discovered in ground water at the subject site in 1986. Since then, the site has been investigated in several phases to define the extent of hydrocarbons in the ground water, and to initiate product recovery. Before this study, however, soil vapor has been sampled only in conjunction with exploratory soil borings at the site (by measuring ambient headspace on soil samples from borings), and not as a separate and unique exploratory technique. There are numerous soil boring logs and ground water monitor wells with which to compare information gathered by soil vapor measurements at this site. The abundance of information available for this site is unique, since most soil vapor studies are conducted as the initial phase of investigation, and little auxiliary information is normally available at the time of study. The abundant soil and ground water information at this site will be used to help interpret information gathered with soil gas sampling.

As discussed later in this paper, the variables which affect soil volatile organic vapor concentration are numerous and complex in their interwoven relationship. It was not anticipated that an absolute quantitative relationship could be established for the effect of each

environmental parameter on soil organic vapor concentration with this study. However if the relative effects of environmental variables may be isolated in field conditions, this information can be used to make at least qualitative determinations when interpreting soil vapor data. Thus it is the purpose of this study to establish or document the comparative effects of environmental parameters and measurement methods on soil vapor concentrations as measured in the field.

Overview of Experimental Methods

A soil vapor survey was conducted on a grid pattern across the site for initial definition of the extent and degree of ground water impact by gasoline. Several different methods of obtaining a soil organic vapor measurement were employed for comparison and determination of the optimum method for the site. A Thermal Environmental Instruments Model OVM 580A hand-held portable photoionization detector was used for measuring total volatile organic soil vapor concentrations in the field. The instrument was calibrated to respond in parts per million to the equivalent of isobutylene concentration. However different compounds exhibit different photoionization responses, therefore absolute quantitation is not possible with this instrument, and measurements were recorded in undefined units referred to in this study as total ionizable vapors, or TIV.

Four "soil vapor ports" were installed at selected locations directly above and lateral to the previously defined free product plume in order to obtain repeated soil organic vapor concentrations at the same location under "undisturbed" conditions, for comparison to soil moisture content and other variables, and also to evaluate the potential value of using permanent-type soil vapor sampling ports in a ground water or soil contamination monitoring capacity. Soil type was recorded at each soil vapor port location, and soil grain size distribution analyzed, so that effects of soil type may be evaluated with other influencing variables. Ambient air temperature, relative humidity, barometric pressure, wind speed, degree of insolation, and depth to fluid (either ground water or floating gasoline) were recorded during each sampling event by correlation to closely located monitoring wells. Soil moisture content was also measured by collecting samples with a soil core and using the wet weight/dry weight method. Soil temperature measurements were also included later in the study. These variables were all compared with repeated soil organic vapor concentration measurements at each sample point in an attempt to determine the relative effect of each variable on soil organic vapor concentrations as measured in a field study, as opposed to laboratory conditions. For the purposes of this study, the concentration of volatile organic compounds in ground water was considered to be constant. A field data collection

form was developed for general usage in soil vapor measurement studies to assist in quality assurance. Ground water samples from several monitoring wells at the site, and soil from the soil vapor port locations were collected and analyzed for benzene, toluene, ethylbenzene and xylene (BTEX) for comparison to soil organic vapor concentrations measured using the PID and a portable gas chromatograph (GC). Vapor samples were also collected from above the water table in these wells for comparison to both the ground water concentration in the well and the concentration of soil vapor near the well.

CHAPTER II

LITERATURE REVIEW

Historical Overview of Soil Vapor Studies

Vapor movement through soils has been studied by others for many years, mostly in an agricultural context. Effects of gas diffusion in soils on plant root respiration has been a topic in early research (Buckingham, 1904; Penman, 1940) and the movement of pesticides through soils has also been of importance to researchers (Ehlers et al, 1969). Detection and mapping of organic vapors in soils have been used as a remote sensing tool in petroleum exploration as early as 1929 (Horvitz, 1985). More recently, the enactment of Subtitle 1 of the Resource Conservation and Recovery Act (RCRA) in 1984 has stimulated interest in the measurement of volatile organics in soil interstices as an indicator of underlying soil or ground water contamination from underground storage tanks as well as from other industrial sites. Soil gas surveys have become a popular (though perhaps not adequately understood) tool for characterization of volatile hydrocarbon releases.

The spatial and temporal variability of many of the factors which affect soil vapor movement make the prediction of actual vapor concentrations in soils

difficult. It is therefore necessary to define the environmental parameters which affect soil vapor movement, and to describe these effects to enable correct interpretation of soil vapor data. Volatile organic vapors in the soil usually emanate from an underground liquid contaminant source, partitioning from the source into vapor and dissolved liquid phases and establishing a concentration gradient from the source to the atmosphere and to the surrounding ground water. The following is a description of a theoretical spill event, included to assist in conceptualizing the soil-water-hydrocarbon-air system.

Dynamics of the Soil-Water-Hydrocarbon-Air System

As liquid hydrocarbon is introduced to the soil it will infiltrate under the influence of gravity mostly as an immiscible fluid, displacing air but not water from the soil. Some lateral movement will occur, the extent and rate of which is dependant on the relative permeability of the soil to water and hydrocarbon, the soil water content, the depth of the unsaturated zone and the presence of macropores, either natural or anthropogenic, in the soil. In general, more lateral movement will occur in finer textured soils and where the unsaturated zone is relatively shallow. A residual hydrocarbon saturation of from 5 to 20 percent of void space is left in the soil, depending on

soil texture and type of hydrocarbon; the coarser the soil texture and the less viscous the hydrocarbon, the lower the residual saturation (Dietz, 1970). Hydrocarbon in excess of the residual saturation will continue to travel downward, until it reaches the saturated-unsaturated zone interface, where it will begin to spread laterally. Eventually the hydrocarbon will occupy a soil volume approximately equivalent to the actual volume of hydrocarbon spilled divided by the residual hydrocarbon saturation. The hydrocarbon body will have a generally circular shape under static and isotropic conditions; the shape will be skewed in the direction of ground water flow or along preferential flow paths (such as macropores or buried ditches). The thickness of the hydrocarbon "layer" will again depend on hydrocarbon viscosity and soil texture, and is thought to correlate with the thickness of the water capillary zone (Dietz, 1970).

Water soluble hydrocarbon constituents will dissolve into the soil solution and meteoric water infiltrating through the hydrocarbon-saturated soil will accumulate soluble constituents and carry them to ground water where they will flow with ground water (by convection) and by dispersion. Movement may be slowed by reversible adsorption to soil solids and natural organic material, and by degradation by soil biota.

Volatile components will evaporate both from the hydrocarbon phase and from dissolved constituents in ground

water into the soil atmosphere, migrating upward if lighter than air, or downward if more dense, by diffusion and convection (Schwille, 1984).

Gas/Liquid Partitioning in Soil Media

Liquid/gaseous separation equilibrium is described by Henry's Law:

$C_V = K_H C_l$ where;

C_V = mass vapor / volume air,

K_H = Henry's Law constant

C_l = mass solute / volume solution.

Henry's Law has been shown to be valid all the way to saturation for many organic chemicals; thus K_H is commonly calculated as the ratio of saturated vapor density to water solubility. The Henry's Law constant is also expressed as the ratio of vapor pressure to dissolved concentration:

$P_v = k_H C_l$, where;

P_v = is vapor pressure and

k_H = Henry's Law constant, expressed in pressure and density terms.

The conversion from k_H to K_H, obtained by using the ideal gas law, is: $k_H = K_H \frac{RT}{M}$, where;

R = the universal gas constant, (J $mole^{-1}$ $^oK^{-1}$),

T = the absolute temperature and

M = the molecular weight of the compound

(Devitt et al, 1987). The boiling point of the compound, which is related to the vapor pressure, also affects

liquid/gas partitioning. Those compounds with high vapor pressure and low boiling point would be more well suited as indicator constituents in soil vapor sampling.

Water solubility of the organic compound has an effect on the concentration of the gas phase. If the compound is highly water soluble, it would tend to dissolve into the soil solution and ground water, rather than evolving into the soil atmosphere, leaving behind less soluble fractions in the remaining hydrocarbon-saturated earth material (Pfannkuch, 1984). The spill "ages" by dissolution, volatilization and degradation by soil micro-organisms; therefore the age of a spill will affect the concentration and identity of constituents in and emanating from the source. A newer spill would have more volatile compounds at a higher concentration. In summary, liquid gas partitioning in the soil is controlled by the concentration, the volatility, (or vapor pressure or boiling point), and the solubility of the liquid constituents, the total gas pressure of the overlying soil atmosphere, and temperature.

Gaseous Flow Through Soil Media

Movement of the evolved vapor phase is in response to two driving mechanisms, diffusion and convection (Hillel, 1982). Diffusion is movement in response to the partial-pressure gradient of each component of a gaseous mixture, and convection is mass movement in response to the total

gas pressure gradient. Air pressure fluctuations which cause convective flow of soil gasses are generally regarded to be a relatively minor determinant of soil aeration except at shallow depths; diffusion has been widely, though not universally, accepted as the dominant mechanism of soil gas exchange with the atmosphere. The rate of diffusion of a gas is described by Fick's Law, which defines diffusive flux (mass/area-time) as equal to the diffusion coefficient (area/time) times the concentration gradient (mass/volume/distance). The diffusion coefficient is a proportionality constant dependant on the physicochemical nature of both the solvent and the diffusing vapor (Hillel, 1982).

Gaseous diffusion through porous media is further dependant on the total porosity of the media, the gas-filled porosity of the media at steady state and the tortuosity of the pore spaces (Buckingham, 1904). This relationship is altered by adsorption at non-steady state (Penman, 1940). Air-filled pore volume decreases as water saturation increases, reducing the area available for gaseous flow, hence reducing diffusion (Millington, 1959). The hysteresis effects of wetting/drying cycles in soils also affect gaseous diffusion (Shearer, et al, 1966). As soil bulk density (degree of compaction) is increased, gas diffusion decreases; this is essentially a function of porosity (Ehlers, et al, 1969). Increasing soil temperature will increase vapor diffusion, by increasing

volatilization of the source liquid, hence volatile vapor concentration, and increasing the kinetic energy of diffusing molecules, as described by Henry's Law.

The movement of organic-solvent vapors from a liquid source through unsaturated porous media is further complicated by adsorption of the gas by media solids and capillary water. Adsorption of gases in the unsaturated zone is also affected by the water vapor content (relative humidity) of the soil atmosphere. Adsorption of organics to soil solids occurs mainly on the free OH groups on silica surfaces (Galkin, et al, 1964), and the primary influence on adsorption of gases by soils has been shown to be soil surface area (Houston, et al, 1989). At very low humidity, organic vapors are strongly adsorbed by soil minerals; as humidity increases the polar water molecules are more readily adsorbed by soil minerals, preferentially occupying adsorption sites and preventing adsorption of the non-polar or more weakly polar organics, until all available adsorption sites are occupied, and adsorption of organics becomes relatively insignificant (Ehlers, et al, 1969,). At about 90% relative humidity, the sorption of organics on soil materials becomes comparable to that in aqueous systems (Chiou & Shoup, 1985). Since the relative humidity of soils is usually between 98-100% (Hanks and Ashcroft, 1980), solid-liquid partition coefficients for non-polar solvents provide good approximations of vapor-solid interactions in soils (Roy & Griffin, 1990).

Changing soil moisture conditions such as those incurred by a rainfall event will complicate analysis of the soil vapor movement. Soil particles will be wetted by the more affinitive water, which reduces exposure of liquid phase hydrocarbons left in the vadose zone. Volatile-laden soil vapor will be expelled to the atmosphere due to displacement by rainwater. The descending water may subsequently pull fresh ambient air into the soil. Some hydrocarbons may be dissolved into the low - dissolved solids rain water as it infiltrates, and the hydrocarbons are thus returned to ground water. Pore spaces are temporarily occupied by a higher concentration of water, blocking off pathways for vapor movement. Surface tension is reversed in the vadose zone; the liquid phase hydrocarbons had been under capillary tension, which would tend to increase volatilization. The infiltrating rain water then exerts a hydraulic pressure, which may cause the fully miscible vapor phase volatiles to temporarily re-dissolve.

The dielectric constant of a material describes the relationship between two charges and the distance of separation of the two charges to the force of attraction. In clays this constant reflects the degree to which the clay will shrink or swell. A high dielectric constant liquid will cause clays to swell, whereas a low dielectric constant liquid would cause them to shrink. Thus exposure to a solvent with a low dielectric constant could cause

clays to shrink, allowing more rapid infiltration and leaving a more permeable pathway for vapors to migrate back upward (Devitt, et al, 1987).

The distance from the liquid source will have an essentially linear effect on vapor concentration, and the vapor phase may not be detectable at a practical depth above the ground water source if the water table is too deep. Figure 1, from Kerfoot and Barrows (1986), illustrates the linear relationship between depth and vapor concentration above a ground-water contaminant plume in Nevada.

It is also possible that petroleum hydrocarbons may be absent in shallow soil gas overlying areas of known gasoline contamination, due to biodegradation of the petroleum compound vapors near the surface (Marrin and Thompson, 1985).

All of the above described processes will affect the shape of the soil vapor "plume" along with vertical and horizontal variations in soil texture and moisture content. For example, local clay lenses may inhibit diffusion, creating a much steeper gradient below the clay than that surrounding the lens, as illustrated by Figure 2. The same effect will be created by man-made low permeability layers such as roads, parking lots or foundations.

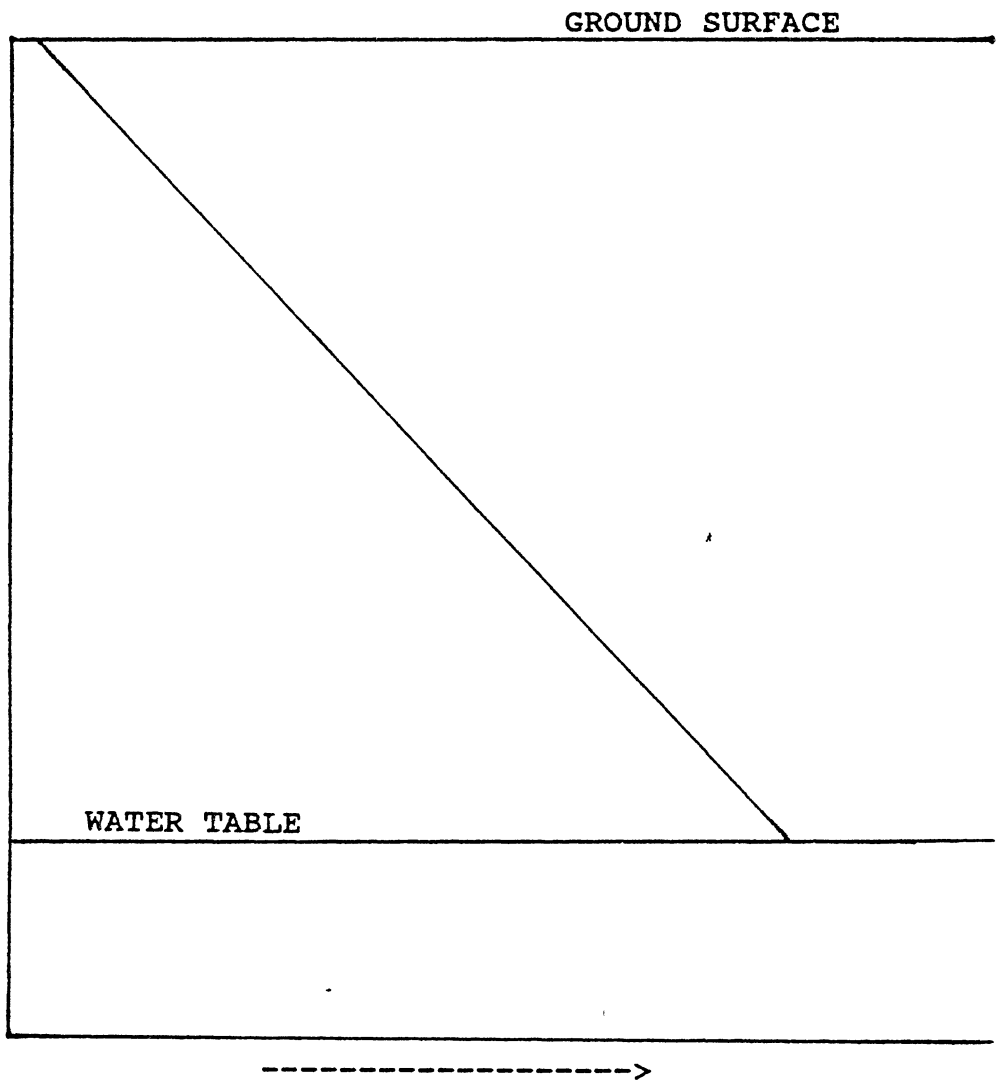


Figure 1. Diagram Showing change in volatile organic vapor concentration with depth

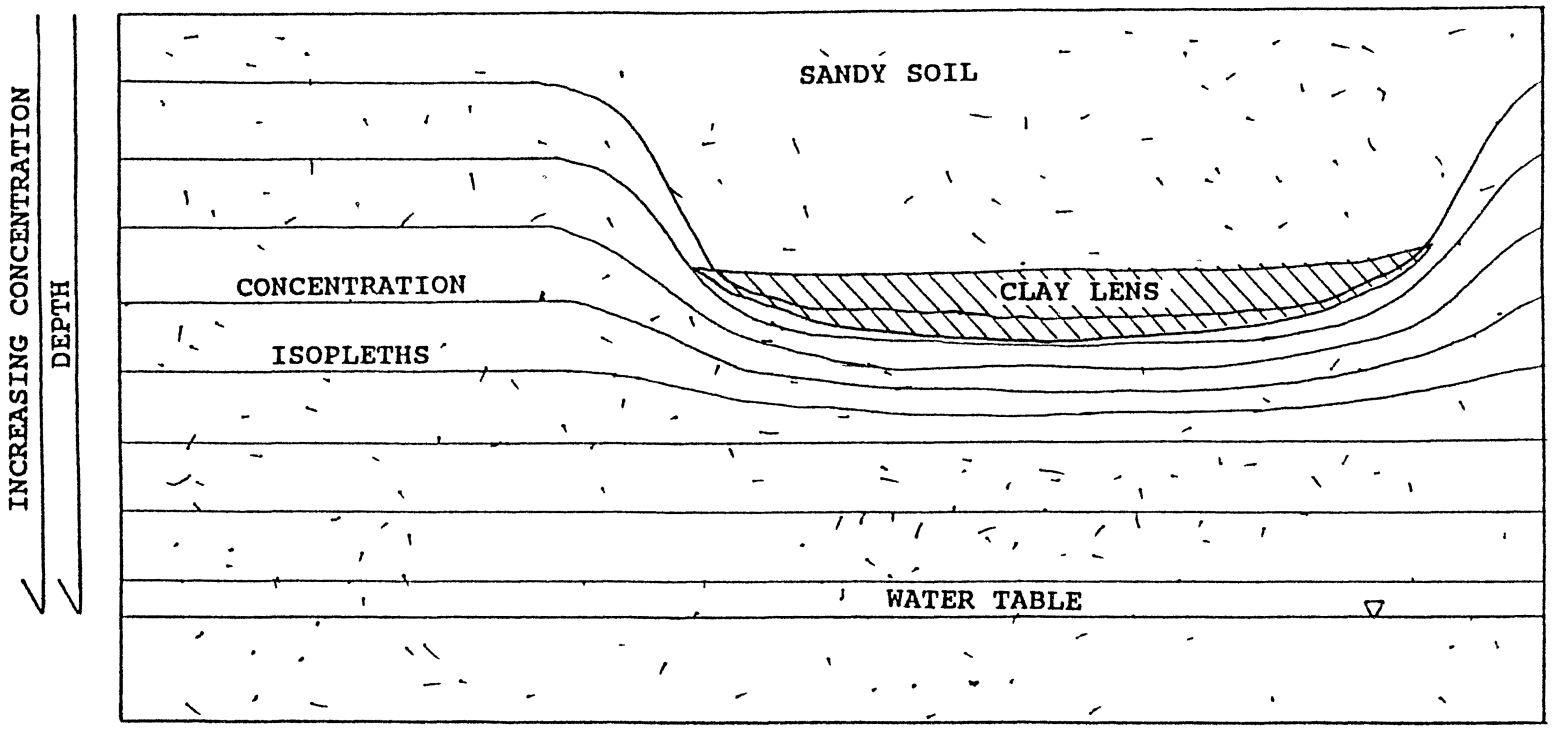


Figure 2. Idealized cross section showing effect of clay lens on organic vapor concentration gradient

Effects of Soil Organic Material

Hydrocarbons in soil are also adsorbed by naturally-occurring soil organic material. Soil organic molecules have high surface areas and very high ionic exchange capacities, which make them relatively "sticky". The effects of adsorption by organics can be approximated by the organic carbon distribution coefficient, K_{OC}, a compound-specific property which relates the tendency of a compound to adsorb out of solution onto organic carbon. Desert soils can be nearly devoid of organics, while some agricultural soils have up to 2 percent organic matter (Devitt, et al, 1987). Most of the organic carbon content of soils is found near the surface, in the root zone. Thus adsorption by soil organics becomes less important with depth in the soil profile, and may not have any significance in areas where the ground water and floating hydrocarbons are at great depth.

Effects of Soil Micro - Organisms

Alteration of organic pollutants by soil micro-organisms (referred to as degradation) can have a pronounced effect on concentration. Different species of soil microorganisms are better able to metabolize different compounds than others; the rate of decomposition is dependant on the difficulty with which the compound is broken down and on the population density and diversity of the soil micro -

organisms (Jamison, et al, 1975). Decomposition of the organics is essentially an oxidative process - thus it is controlled by oxygen in the soil as the limiting factor. The rate of oxygen diffusion in the soil will therefore have a limiting effect on degradation (Baehr and Corapcioglu, 1984). The straight-chain paraffinic hydrocarbons will degrade most rapidly, followed by the branched chain paraffins, the cyclo-paraffins and the aromatic hydrocarbons (American Petroleum Institute, 1972). Halogenated organic compounds have been shown to degrade least rapidly in soil, in part possibly because of their high density. Higher density and lower solubility are both signatures of increasing halogenation of organic compounds. A compound with a lower density than water will sink in an aquifer; since biotic activity decreases with depth, the compound will have less exposure to degrading micro-organisms, and will be less prone to volatilize. Thus halogenated, high density compounds are not good candidates for soil vapor monitoring.

Summary

Research has shown that volatile vapor concentrations may be predicted by mathematical modeling with reasonable accuracy when all of the related parameters are known or held constant (Silka, 1986). The source material properties are of very significant importance to the collection, analysis and interpretation of soil vapor data,

and should not be ignored when undertaking a soil vapor study (Tillman, et al, 1988).

This study concentrates on how the properties of the physical environment affect the occurrence and movement of volatile organic vapors in the soil. The properties of the source material are considered to be essentially unchanging during the course of this study, and therefore are discussed only briefly. Table I lists environmental parameters which affect the movement of organic vapors through soils. With knowledge of the factors which affect the occurrence and movement of organic vapors in soil, a decision can be made as to the suitability of a spill site for investigation by soil vapor methods. The ideal spill site would have the following characteristics:

IDEAL SOURCE MATERIAL CHARACTERISTICS

1. low density (<1 g/cm^3, floater)
2. low viscosity
3. fairly high volatility
4. moderately low water solubility
5. low potential for degradation
6. fairly new spill

IDEAL SITE CHARACTERISTICS

1. coarse grained soils
2. moderately low soil moisture content
3. isotropic soil characteristics
4. fairly shallow ground water
5. little water table fluctuation.

TABLE I

LIST OF ENVIRONMENTAL FACTORS AFFECTING MOVEMENT OF ORGANIC VAPORS THROUGH SOILS

1. soil porosity (which is a function of soil texture)
2. soil pore shape and size
3. air-filled porosity
4. volumetric water content
5. soil water retention characteristics
6. depth to ground water
7. organic content of soils
8. adsorptive properties of soil minerals
9. air and soil temperature and temperature gradients
10. ground water flow (direction, velocity and gradient)
11. fluctuations in water table elevation
12. aquifer lithology
13. rainfall events
14. barometric pressure (its point-in-time value, as well as the frequency and magnitude of changes)
15. wind velocity and duration
16. atmospheric relative humidity

Variations from these ideal conditions will create problems either in collecting or interpreting soil vapor data; therefore it is extremely important to consider these factors when designing and implementing a soil vapor study.

Collection and Measurement of Soil Organic Vapor

Sample Collection Methods

Various methods have been used to measure organic constituents in the soil atmosphere, for various different purposes. Soil vapor sampling methods may be classified within the following categories:

1. soil core sampling
2. ground probes
3. sorptive sampling
4. surface flux chambers
5. headspace sampling of subsurface structures
6. permanent-type soil vapor ports.

The following sections review each of these methods, their applications, advantages and limitations.

Soil core sampling. Collection of soil cores for analysis of organic constituents has been used in exploration for petroleum accumulations for many years, both on-shore and off-shore (Horvitz, 1985). This method involves grab sampling a soil core using a hand auger or other coring device, and preservation of the core in a

sealed container for later analysis. A variety of containers have been used, including heat-sealed polyethylene bags, glass jars and soldered cans. The container may be partially filled with soil, and vapors allowed to diffuse into the headspace, or the container may be tightly packed with "undisturbed" soil, and a vapor sample extracted from the soil interstices. Opinions vary regarding preservation of the soil samples. Degradation of samples not refrigerated has been documented (Smith and Ellis, 1963), however Horvitz reported that minimal headspace in the sample container eliminated the need for refrigeration. The preserved samples are then transported to a stationary laboratory facility, where a vapor sample is extracted with a syringe or pump, and analyzed by gas chromatography or mass spectrometry.

Advantages to soil core sampling for organic vapor analysis are that it requires little technical expertise and can be accomplished without the need for highly specialized equipment. The method is limited, however, in that it is better suited for analysis of adsorbed organics than free interstitial organics; headspace in the container will lead to desorption of organics from the soil particles. Volatiles may be lost from the sample during collection or removal from the container, or degraded during storage. Rocky, loose or sandy soils may not be well suited for collection by coring devices (Devitt, et al, 1987).

Ground Probes. Ground probes have been used as early as 1915 to extract soil vapor samples (Russell and Appleyard, 1915). This method involves driving a hollow tube of various design into the ground, and extracting a vapor sample through a port at the surface. The probe may have a tip with perforations to allow entrance of the soil vapor or may be of a sleeve-type design which allows the tube to be retracted, exposing the soil surface to the inside of the tube. A vapor sample may be pumped from the probe into a container, or extracted for direct analysis. A very wide variety of probe designs have been employed, from a simple plugged core hole to very low-volume designs intended to retrieve an absolutely representative sample of the soil vapor by eliminating dilution (Devitt et al, 1987).

Advantages to using ground probes to sample soil vapor are many. Ground probes can rapidly provide a vapor sample which can be analyzed immediately, eliminating degradation or dilution of the sample in storage. In theory, soil vapor samples from ground probes can be truly representative of the soil atmosphere, and not significantly influenced by desorption of compounds adsorbed to soil materials. The depth of investigation may be varied to penetrate impermeable layers or to increase sensitivity.

Limitations to the use of ground probes are few as compared with most other methods. Very wet or clayey soils

restrict the flow of soil vapors into the probe, making collection of a representative vapor sample difficult or impossible, and very rocky soils prevent probe penetration. Obtaining a representative vapor sample requires careful design of the probe: leakage of ambient air down the probe shaft is a problem, and probe perforations can clog with soil material, especially in fine grained soils. The method is labor intensive and breakage of probe assembly pieces is common due to the force required for insertion and removal.

Sorptive Sampling. Sorptive sampling usually involves the burial of a collection device, relying on diffusion to carry organic vapors to a concentrating medium inside an inverted test tube or similar container to trap upward-diffusing vapors. Activated charcoal or some other adsorptive material is used to concentrate the vapors. The container is exhumed and the adsorbent material is then desorbed by thermal or solvent methods for analysis, usually by GC (gas chromatography) or GC/MS (gas chromatography/mass spectrometry) (Zdeb, 1987). Sorbents may be used in conjunction with soil probes, either "passively" or "dynamically". Passive sampling relies on diffusion to transport VOC's to the sorbent; dynamic sampling utilizes pumping of soil vapor to collect a sample. In passive sampling with a probe the probe is used to insert the sorbent container, then is capped and left in

place for the duration of the sampling event. In dynamic sorptive sampling with a probe, soil vapor is pumped from the probe through the sorbent (Zdeb, 1987).

Sorptive sampling is best applied to areas where organic vapor concentrations are expected to be very low, since the samplers may be left in the ground longer to detect lower concentrations. Areas of very tight soils, which do not respond well to dynamic soil probe methods, may be considered to be good candidates for passive sorptive sampling. The method is limited by the long time required for sample collection and by the disturbance of the sample site (Devitt, et al, 1987).

Surface Flux Chambers. Surface flux chambers are enclosures placed on the ground surface to measure gaseous emissions from a known surface area. The chamber is swept with a carrier gas and the gas exiting the chamber is collected for analysis; the emission rate is calculated from the concentration of the exiting gas and the flow rate through the chamber. Figure 3 illustrates a surface flux chamber (Schmidt et al, 1983).

Surface flux chambers are well suited for use in determining population exposures to ground emissions. Disturbances to the soil and emission processes are minimal with this technique, and the technique is applicable to most soil types. Sampling can be fairly quick and the

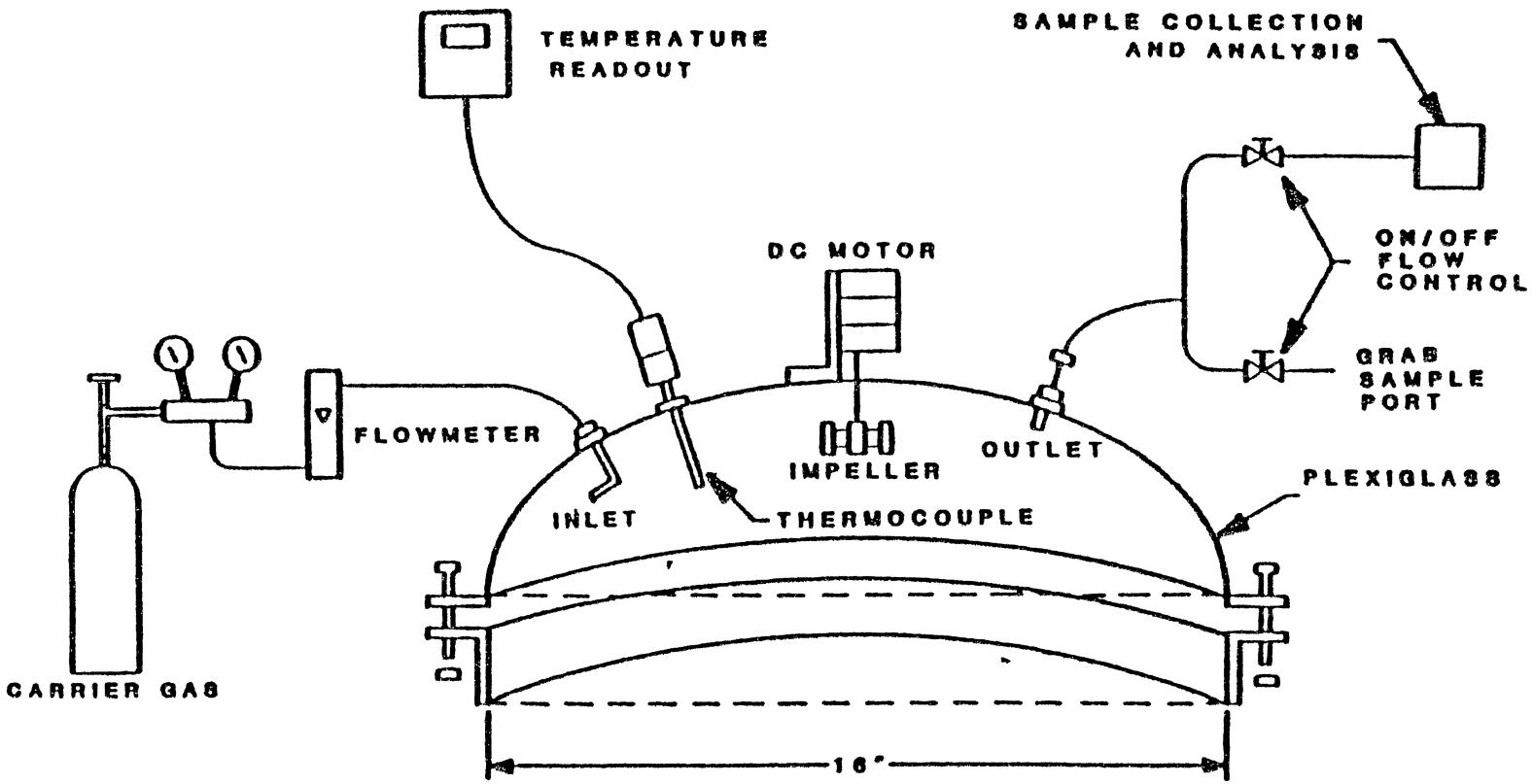


Figure 3: Diagram of surface flux chamber
(from Schmidt, et al, 1983)

equipment is relatively simple. Concentrations of hydrocarbons at the surface are normally much lower than those in the subsurface, so low concentrations at depth limit the use of this method. Emissions are diluted by the carrier gas, which decreases the method sensitivity (Devitt, et al, 1987). Surface flux chambers are thus not well suited as a method for spatial characterization of hydrocarbon impact.

Headspace Sampling of Subsurface Structures. Structures which have enclosed space below ground level, such as sewers, utility vaults or wells will collect soil vapor as it diffuses toward the atmosphere. This vapor can be sampled to make a positive/negative determination as to whether the underlying soil or ground water contains volatile organics. Headspace sampling is useful as a "first-look" indicator of subsurface volatiles, but its usage is fairly limited. The obvious first requirement is that suitable structures must be present at the subject site. A negative response to headspace vapor sampling is inconclusive in that it does not guarantee the absence of hydrocarbons in the underlying soil, since the sampled structure may not be sufficiently sealed to maintain a measureable concentration (Devitt, et al, 1987).

Soil Vapor Ports. The final method of soil vapor measurement discussed in this paper is the use of soil vapor ports, or permanent-type probes. These resemble a

dry well in construction. They consist of a length of tubing inserted into a borehole (which does not penetrate the water table) with a sand filter pack and an annular seal of bentonite slurry or cement-bentonite grout. Figure 4 illustrates a typical installation. These sampling devices are left in the ground, much like a monitor well, in order to measure soil organic vapors over time. Depending on the number and placement of ports, they may be used for the following purposes: to assess the extent of subsurface contamination; to chemically characterize the contamination; to study migration patterns of soil organic vapors; to assess the effectiveness of remediation activities; or to monitor the effects of soil properties and/or variables which change with time, such as weather conditions as in this study. The ports may be nested, with several different lengths of tubing in the same hole, and an annular seal above each section of tubing, in order to monitor changes in soil vapor concentration as a function of depth (Yeates and Nielsen, 1987).

Analysis Instrumentation

Soil vapor samples may be measured to determine the presence or concentration of organics with a variety of instruments, ranging from a few dollars in cost to many thousand. Generally speaking, the more sophisticated the instrumentation, the more accurate, precise and reliable are the results.

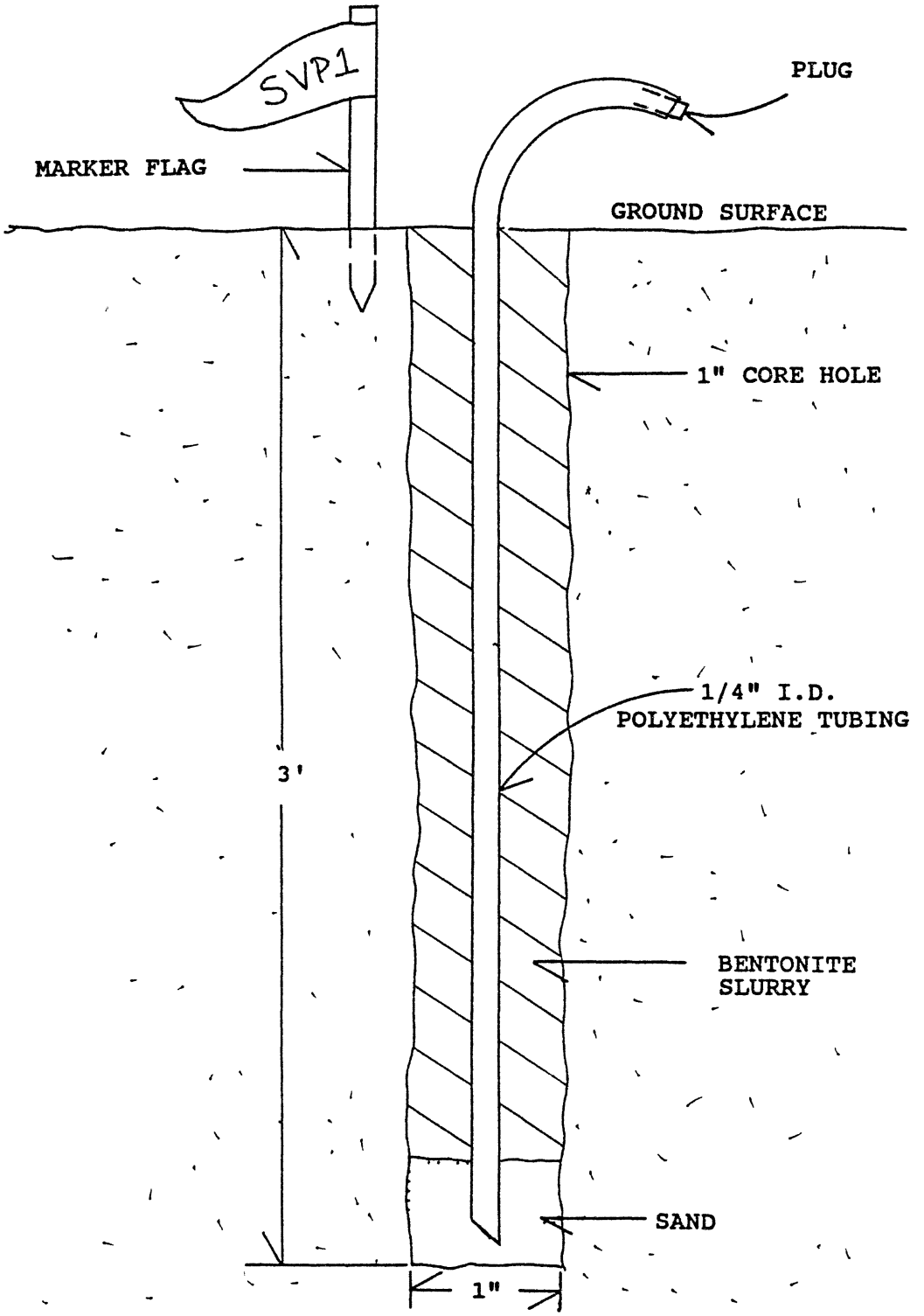


Figure 4. Soil vapor port construction Diagram

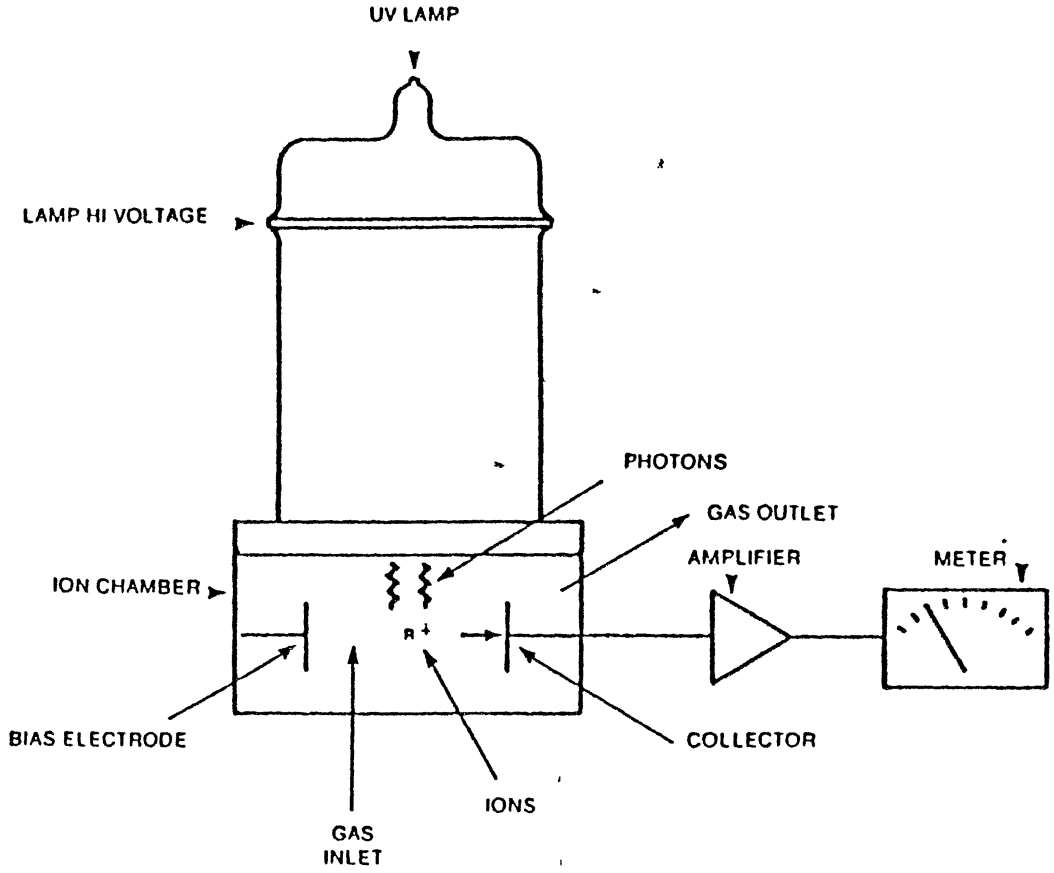
The first step in soil gas sampling, after selecting a sample collection method, is to withdraw a vapor sample from the sampling device. Air sampling pumps and vacuum pumps are commonly used for this purpose. Hand-held photo-ionization detectors and some portable gas chromatographs contain their own pump, and a sample may be directly withdrawn for measurement by one of these devices. Photo-ionization detectors (PID's) pump the vapor into a chamber where it is exposed to a specific wavelength and intensity of ultraviolet light (the instrument used in this study is equipped with a 10.0 electron-volt UV lamp). The organic molecules absorb photons of sufficient energy to release an electron, and thus become a positive ion. A positive polarizing electrode moves the ions to a collector electrode; this movement creates an electrical current which is amplified and displayed by the digital readout of the PID. The current is proportional to the concentration of gases in the ion chamber and the sensitivity of the gases to photoionization. (The ionization potential of atmospheric gases oxygen, nitrogen and carbon dioxide range from 12.0 to 15.6 eV and are not ionized by the 10.0 eV lamp). Table II lists the relative sensitivity of several groups of chemicals to photoionization. Figure 5 (from H-Nu Systems, 1986) is a gross schematic illustrating the construction and function of a typical photoionization detector.

TABLE II

RELATIVE PHOTOIONIZATION SENSITIVITIES FOR GASES
(from H-Nu Systems PI-101 Operations Manual)

Chemical Grouping	Relative Sensitivity*	Examples
Aromatic	10	Benzene, Toluene, Styrene
Aliphatic Amine	10	Diethylamine
Chlorinated Unsaturated	5-9	Vinyl Chloride, Vinylidine Chloride, Trichloroethylene
Carbonyl	7-9	MEK, MiBK, Acetone, Cyclohexane
Unsaturated	3-5	Arolein, Propylene, Cyclohexanone, Allyl Alcohol
Sulfide	3-5	Hydrogen Sulfide, Methyl Mercaptan
Parrafin (C5-C7)	1-3	Pentane, Hexane, Heptane
Ammonia	0.3	
Paraffin (C1-C4)	0	Methane, Ethane

* Note: Relative sensitivity = meter reading when measuring 10 ppm of the listed gas with instrument with 10.2 EV probe calibrated for 10 ppm of benzene, span pot setting = 9.8 for direct reading of benzene.



(from H-Nu Systems, 1986)

Figure 5. Diagram showing components of a photoionization detector

Flame ionization detectors (FID's) use a flame, usually with a hydrogen carrier gas, to ionize the organic vapors; they are otherwise operate in much the same way as PID's. These portable hand-held instruments are also referred to as organic vapor analyzers, or OVA's; they provide a single value indicative of the concentration of the sum of the individual vapor constituent compounds. OVA's are nominally considered accurate to the parts per million (PPM, mg/l) range.

Gas chromatographs (GC's) operate in a similar fashion, however they are also fitted with a packed capillary column to separate the sample constituent compounds by molecular weight, allowing a more detailed analysis. Some portable GC's are equipped with an oven to hold temperature constant, and elevate it for better constituent separation. Portable GC's are nominally considered accurate to the parts per billion (PPB, ug/l) range.

Adsorbents such as activated charcoal or porous polymers (such as Tenax) are sometimes used to concentrate organics from vapors for later desorption and analysis (Zdeb, 1987). Problems with this method are: incomplete adsorption, incomplete desorption, and artifact formation through reaction during thermal desorption or by reaction with the adsorbent material.

Another type of device sometimes used for immediate vapor sample analysis is the Draeger tube, which is a tube

filled with a colorimetric reagent. A specific volume of vapor is drawn through the tube, and the hue, intensity or extent of the color change indicates the range of concentration of organics in the vapor sample. These can be constituent-specific; however they are limited in their precision, and are best suited to measurement at higher concentrations.

If not immediately analyzed, the vapor sample must be contained and transported for analysis at a later time. Vapor sample containers may be plastic (usually Tedlar) bags or stainless steel, glass or Teflon canisters of varying configuration. Materials should be non-reactive and opaque containers are best, as organic vapor samples have been shown to deteriorate with exposure to light. Container durability depends on the length of transport required from sample site to measurement. The container should be well sealed to prevent leakage, dilution or contamination of the sample. The longer a sample must be stored, the greater this requirement becomes. The contained sample may be measured at a stationary location on-site with a portable gas chromatograph or a mobile laboratory chromatograph, or it may be transported off-site to a permanent analytical laboratory if the highest precision and accuracy is required. A well-equipped analytical laboratory is capable of quantitation of many compounds to the parts per trillion range (Devitt, et al, 1987).

Selection of sample collection and analysis methods depends on the objectives of the study, as well as time, equipment and budget constraints. For many projects, extreme precision is unnecessary, and the hand-held OVA's are sufficiently precise, as well as convenient. They may also serve well as a screening device in situations where higher precision and documentation are required. When using soil vapor as a remote sensing method to characterize ground water impact, it is prudent to utilize the most sophisticated analytical methods available, as the information obtained may be effectively used to save money in later phases of investigation, such as siting monitor wells, and in interpretation of later ground water analyses. Constituent-specific data may then prove to be invaluable (Tillman, et al, 1989).

CHAPTER III

SITE DESCRIPTION

The geology, topography, surface and subsurface hydrology, soil type, temperature, precipitation, evapotranspiration, and wind intensity and direction are all factors which affect the occurrence and movement of soil vapor in the subsurface. These parameters are described for the subject site in this chapter.

Site Location

The bulk fuel loading facility is located in the southeastern part of Garvin County, Oklahoma, near the town of Wynnewood (Figure 6). Figure 7 is an aerial photograph of the site. Garvin County is located in south central Oklahoma and is part of the Osage Plains Region which is a southwestern extension of the Central Lowlands Region. The Osage Plains Region is subdivided into several subregions in Oklahoma. The subject site area lies within the Cross Timbers subregion.

Physiography and Topography

The bulk fuel loading facility is located in the Central Lowlands section of the Great Plains Physiographic Province. Most of this area is a relatively flat,

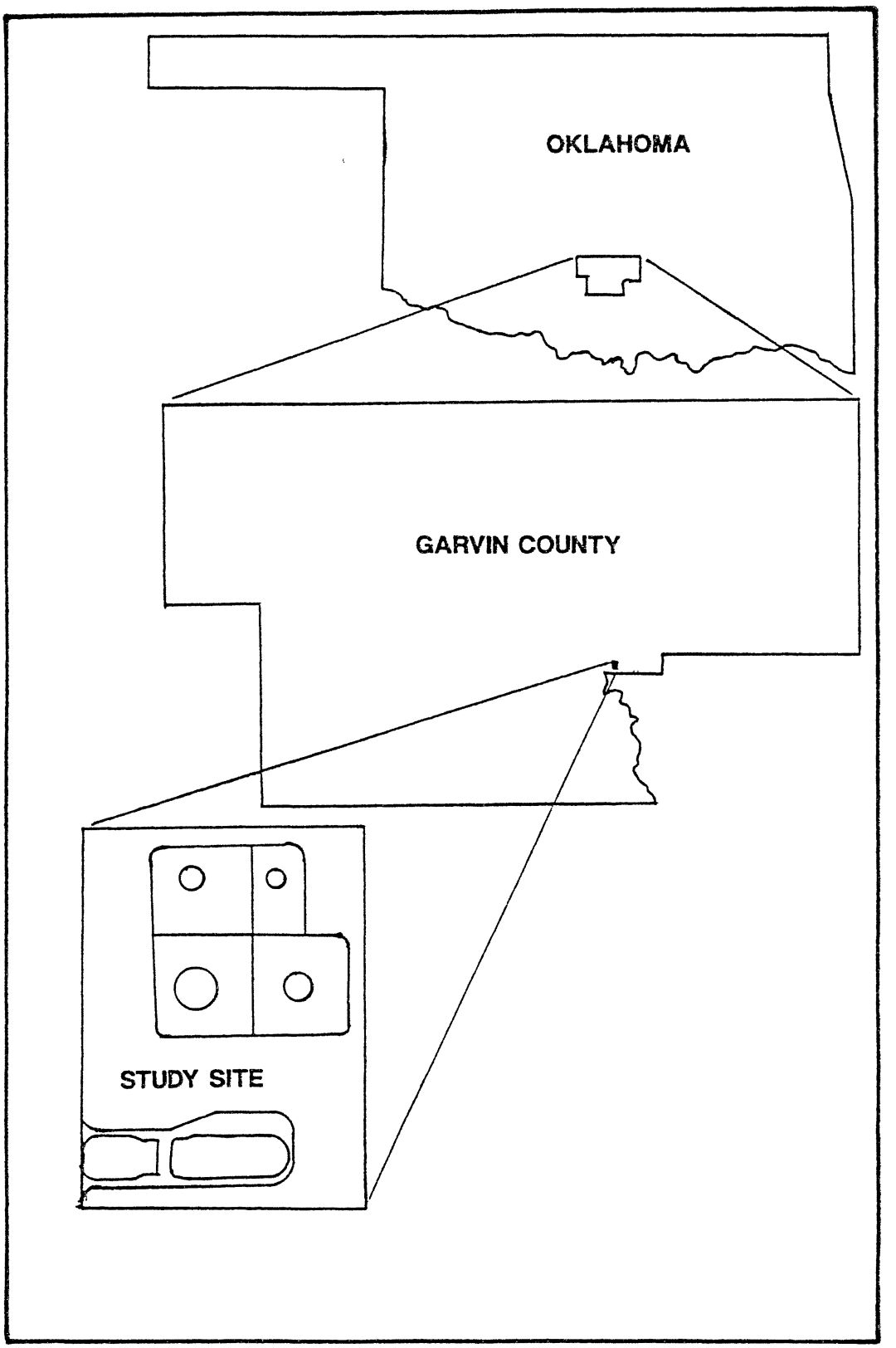


Figure 6. Study site location map

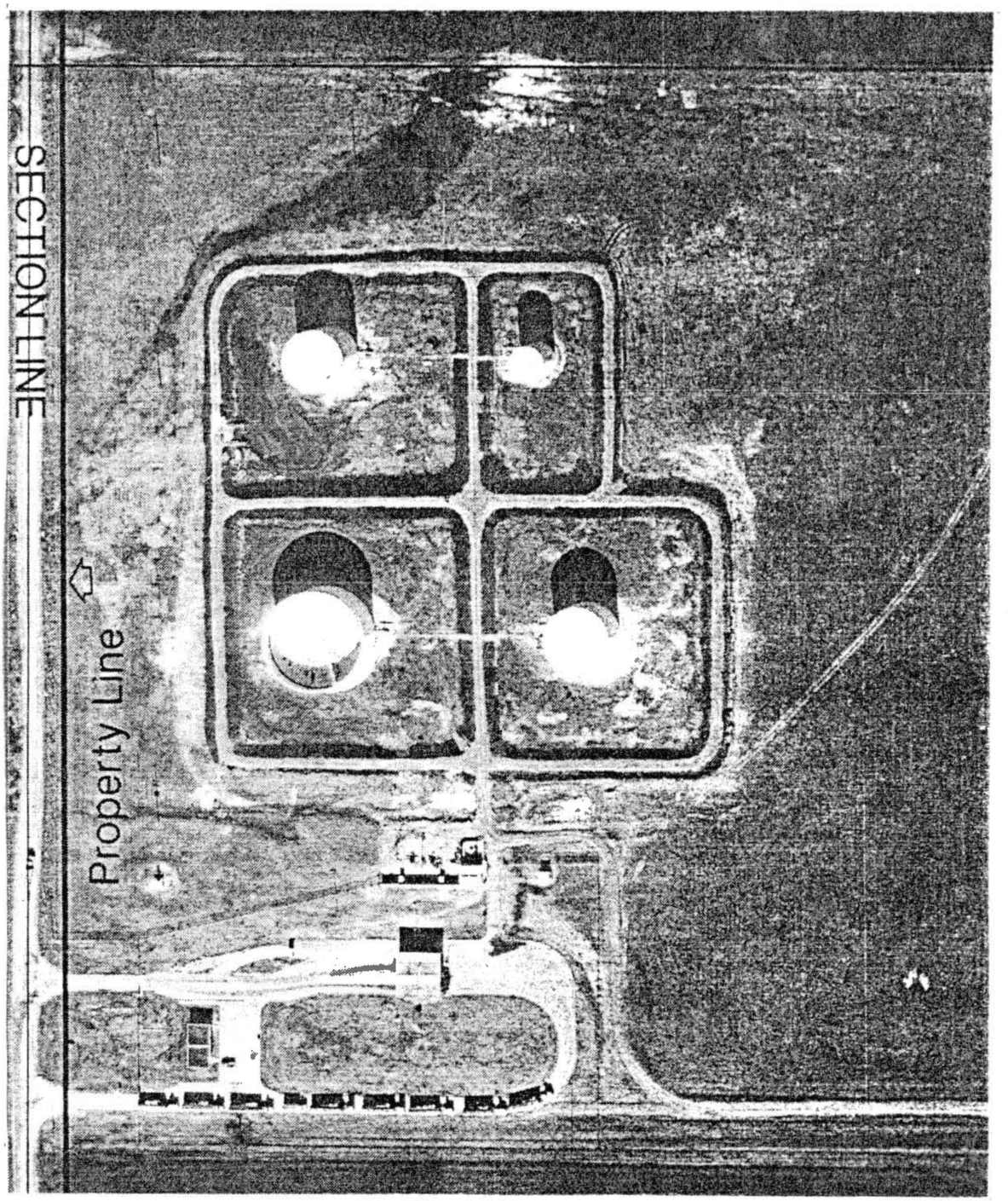


Figure 7. Aerial photograph of the study site

featureless plain developed upon Paleozoic and Mesozoic Age sedimentary formations, and is characterized by nearly horizontal shale, sandstone and limestone units. The less resistant shales generally form the broad shallow valleys while the more resistant limestone and sandstone units form the small intervening ridges (Hart, 1974). The portion of the Central Lowlands in the area including the subject site is locally referred to as the Central Redbed Plains. The subject site is located in a gently sloping surface within the Washita River flood plain, which is incised into the surrounding Oscar Formation shales. The area is bounded on the west by the Washita River, and to the south and east by the Arbuckle mountains. Figure 8 shows the location of Garvin County in relation to the geologic provinces of Oklahoma.

The topography at the subject site (Figure 9) ranges from approximately 845 feet above mean sea level (MSL) at the southeast, to approximately 834 feet above MSL at the northwest. This difference in elevation occurs at a regular progression over a distance of approximately 700 feet, resulting an average grade of approximately 1.6 percent. The topography is broken by man-made structures, including an oval-shaped roadway for fuel-hauling trucks and 4 dikes around large gasoline storage tanks. The area surrounding the site, shown by Figure 10, from U.S.G.S., is quite flat, with a gentle slope to the northwest.

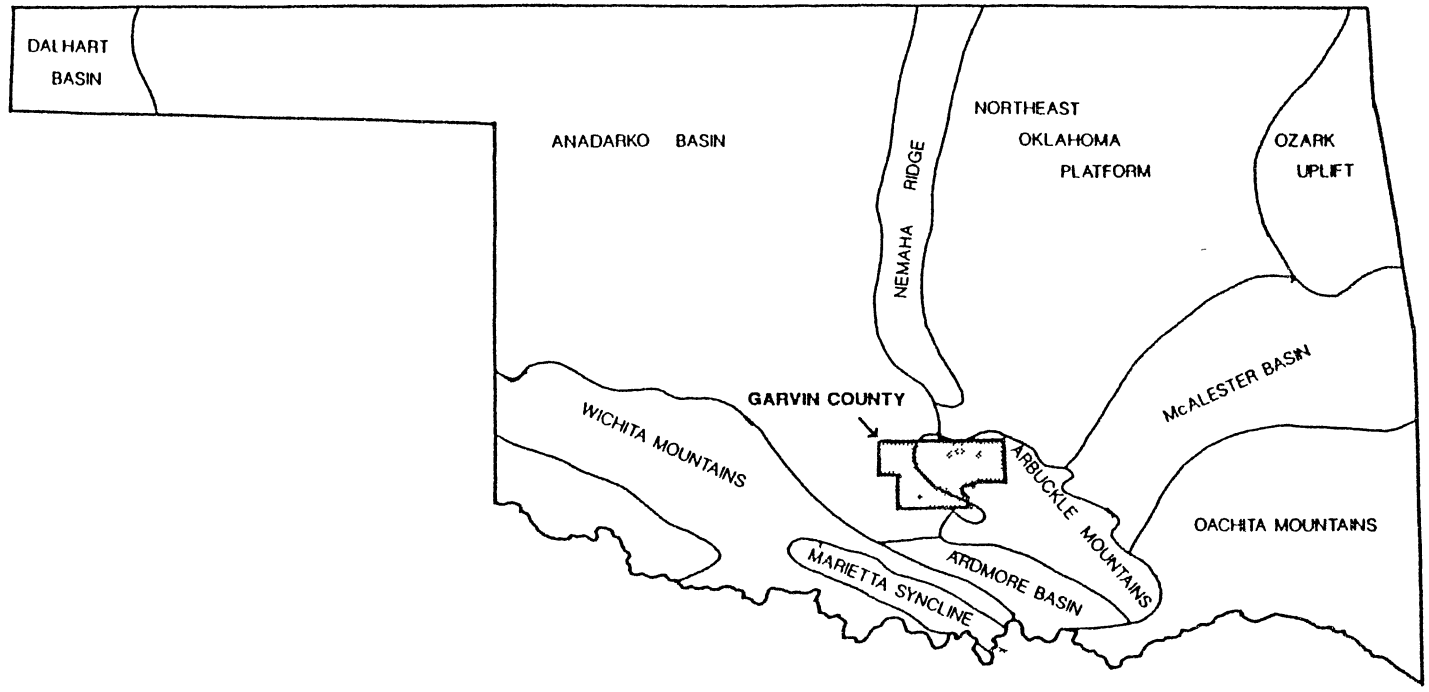


Figure 8. Index map showing location of Garvin County in relation to geologic provinces of Oklahoma

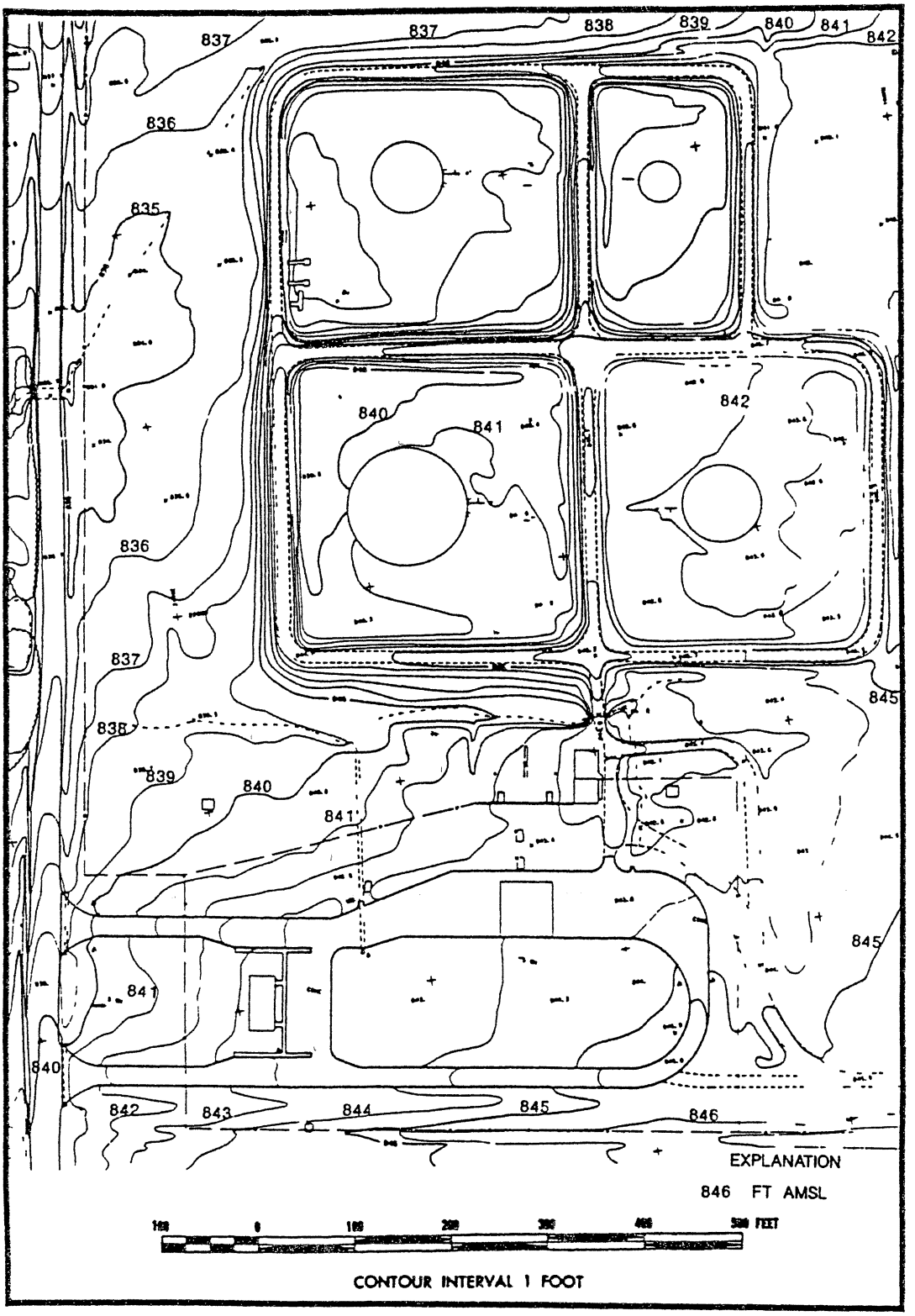


Figure 9. Site topographic map

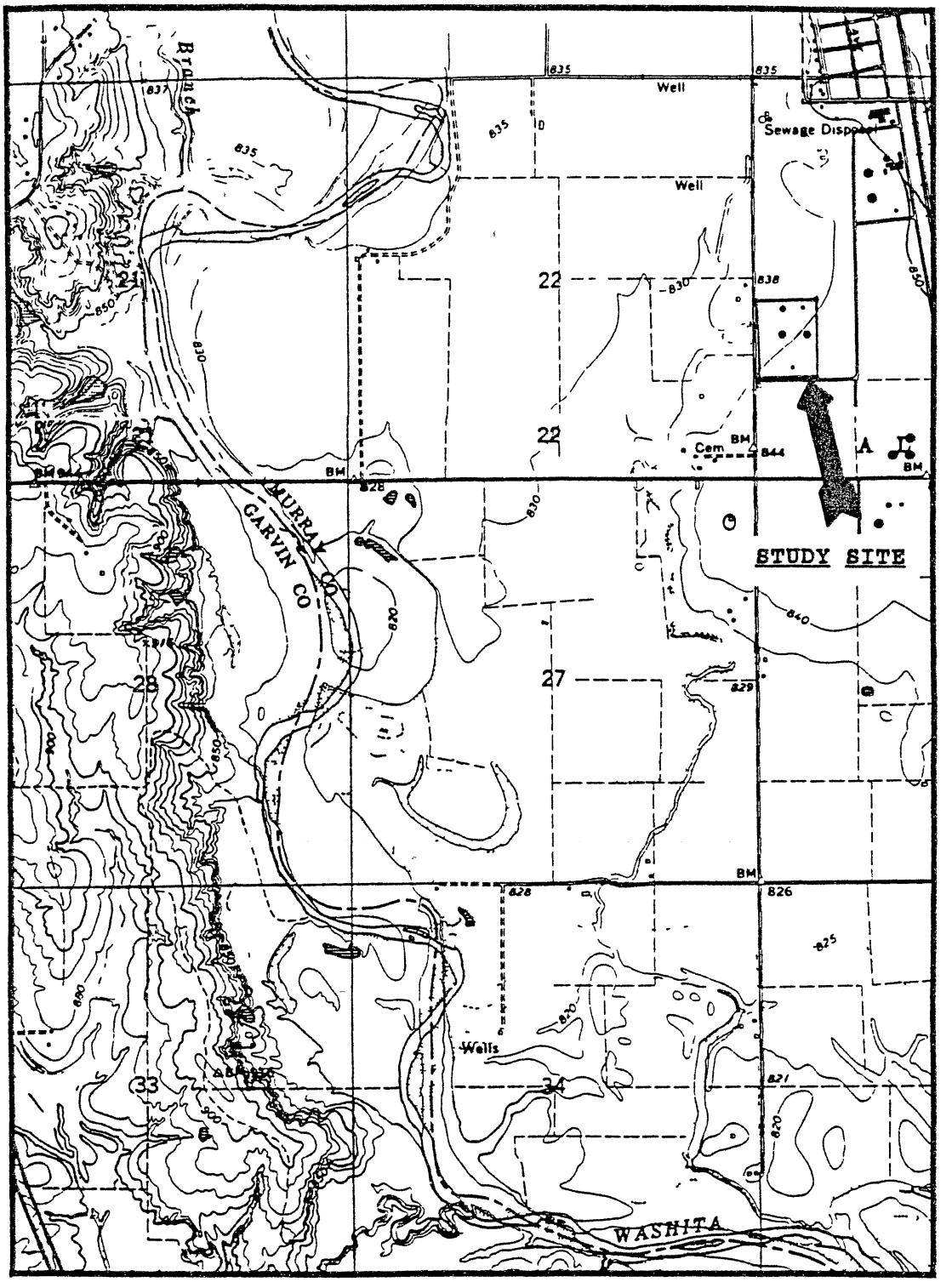


Figure 10. Area topographic map (from U.S.G.S.)

Geologic Setting

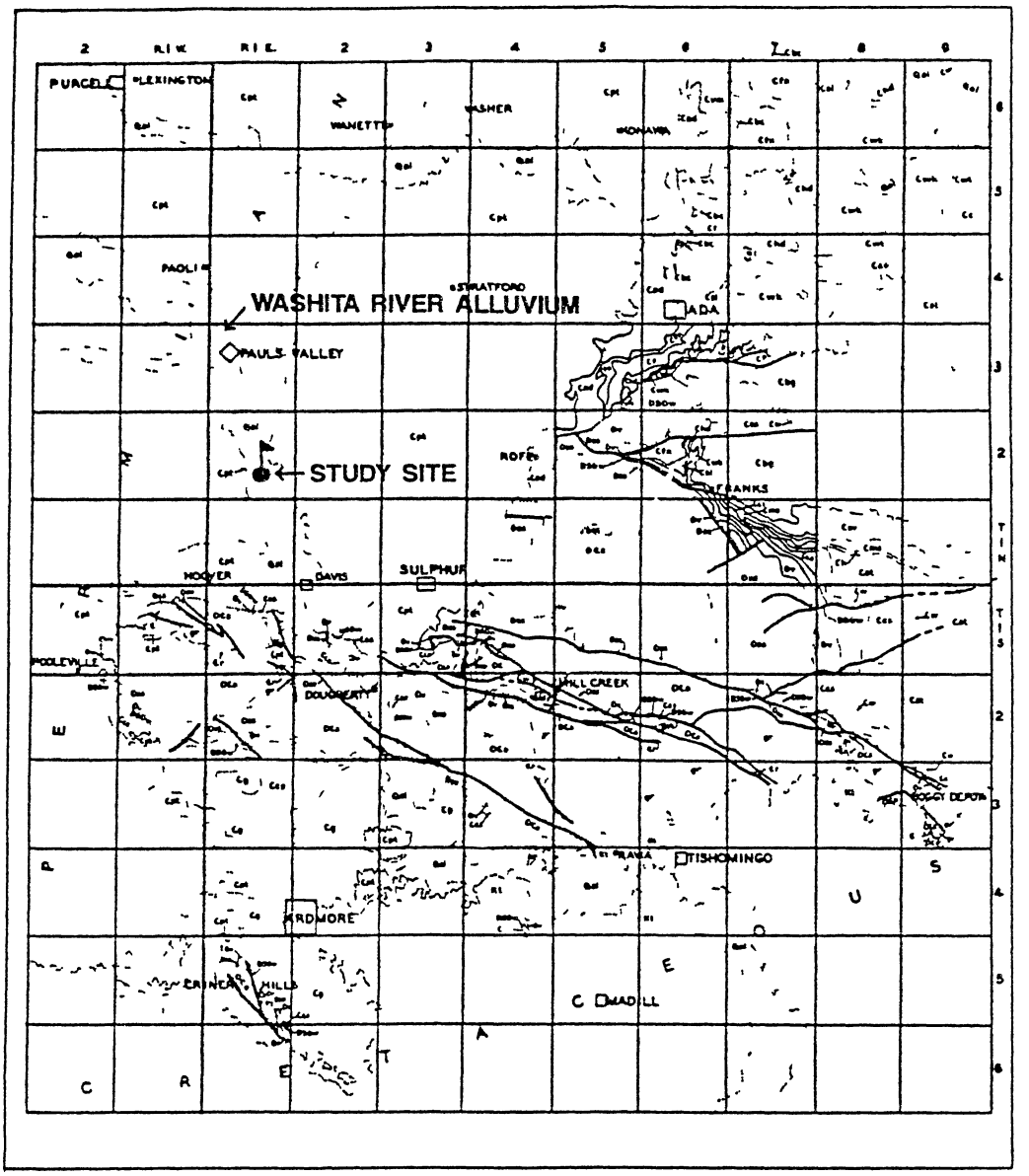
Structural Geology

The two major structural features in Garvin County are the Anadarko basin and the Arbuckle anticline. Figure 11, from Ver Wiebe, 1952, shows the study site in relation to these and other nearby structural features. As shown by this figure, there are no major faults or other structural features close to the study site; the site lies on a gently westward-dipping monocline.

Geologic History

After erosion of an ancient land surface to Precambrian granites, Middle Cambrian volcanic flows were deposited on the granite in the western part of the Arbuckle Mountains. A geosyncline began to develop in the Arbuckle Mountains and Criner Hills area, and many thousands of feet of Cambrian-Ordovician sediments were deposited in the deep sea which covered that area. The geosyncline extended westward into what is now termed the Anadarko basin. On the north flank of the Anadarko basin and in the northern part of the Arbuckle area shallow-water conditions prevailed, and the sediments deposited in these regions were much thinner than those in the geosyncline (Carter, 1979).

Many unconformities developed in this region during the Silurian, Devonian, and Lower Mississippian; these



FROM VER WIEBE, 1952

Figure 11. Map showing structural features near study site area

rocks do not seem to show subdivision into geosynclinal and shelf facies (Carter, 1979).

The geosyncline again became prominent during Late Mississippian and Pennsylvanian time. The uplifting of the Criner Hills and northern Arbuckles Mountains began in Early Pennsylvanian time, with most of the movement taking place in the Criner Hills. In Late Pennsylvanian time the Arbuckle and Tishomingo anticlines formed, creating numerous associated faults and synclines (Carter, 1979).

During Permian time the Anadarko basin remained intact, with the Arbuckle Mountains and Criner Hills slightly above sea level, undergoing erosion. The entire area was probably close to or above sea level, undergoing erosion throughout the Triassic, Jurassic, and Cretaceous periods (Carter, 1979).

The rocks of the Dissected Coastal Plain were deposited during the Cretaceous after inundation by ocean from the south. The entire area was uplifted gently after Cretaceous time, giving a southward regional dip to the Cretaceous beds, as well as many smaller scale local structures (Carter, 1979).

During the Pleistocene ice ages large rivers flowed over the region from the northwest, depositing gravel and sand. The continental glaciers of the ice ages did not advance as far south as Oklahoma, but their repeated advances and retreats had a major influence on southern Oklahoma river flow. As the glaciers advanced, stream flow

diminished and the rivers deposited sediments in their channels. Flow increased during glacial retreats due to increased melt water, and the previously deposited sediments were eroded. Many terrace levels were formed along the present stream valleys as a result of this cycle (Hart, 1974).

Stratigraphy

The Central Redbed Plains are composed of Pennsylvanian and Permian age sedimentary formations. Gypsum, dolomite, and sandstone form sharp east-facing escarpments, and shale forms the gentler slopes. Dip is to the west-southwest at approximately 20 to 90 feet per mile. Along the Washita River and its tributaries lie alluvial, colluvial, and terrace deposits of Quaternary age. The stratigraphy in the vicinity of the subject site consists of Pennsylvanian shales, sandstones, thin marine limestones, and local conglomerates. The upper-Pennsylvanian geological formations consist of (in descending order), the Oscar Group, the Vanoss Group, the Ada formation, and the Vamoosa Formation. Figure 12 is a generalized regional stratigraphic column for the area. An east-west regional geological cross-section of the Permian-Pennsylvanian bedrock in the area is shown in Figure 13, and a map of the bedrock geology in the area is shown in Figure 14 (after Hart, 1974).

(Modified after Hart, 1974)

AGE	SYSTEM	STRATIGRAPHIC UNITS	ESTIMATED THICKNESS, feet	LITHOLOGY	WATER-BEARING PROPERTIES
RECENT	QUATERNARY	ALLUVIAL & TERRACE DEPOSITS	30±	Gravel, sand, silt & clays in alluvial and terrace deposits adjacent to Washita River. Thickness ranges from 0 to 85 feet and averages 60 feet in the Wynnewood area.	Alluvial and Terrace deposits along Washita River may reach 85 feet thick. Wells generally yield 10 to 100 gpm. Water quality generally fair to good Dissolved solids range from 500 to 1000 mg/l.
PALEOZOIC	UPPER PENNSYL-VANIAN	OSCAR GROUP	500±	Predominantly shales, red-brown to gray with thin sandstone and lime-stone beds present	Typically low permeability shales. Variable water quality but typically fair to poor. Yield only small quantities of water to wells.
		VANOSS GROUP	900±	Predominantly shales, maroon, with thin beds of arkose sandstones and limestone conglomerate.	Probably will yield only small quantities of poor quality water to drilled wells
		ADA FORMATION	1400±	Shales, red brown to gray with bituminous sandstones & limestone conglomerate.	Probably will yield only small quantities of poor quality water to drilled wells
		VAMOOSA FORMATION	1000±	Shale, sandstone, & chart conglomerate, red-brown to buff fine to coarse grained sandstone.	Probably will yield only small quantities of poor quality water to drilled wells

Figure 12. Regional stratigraphic column

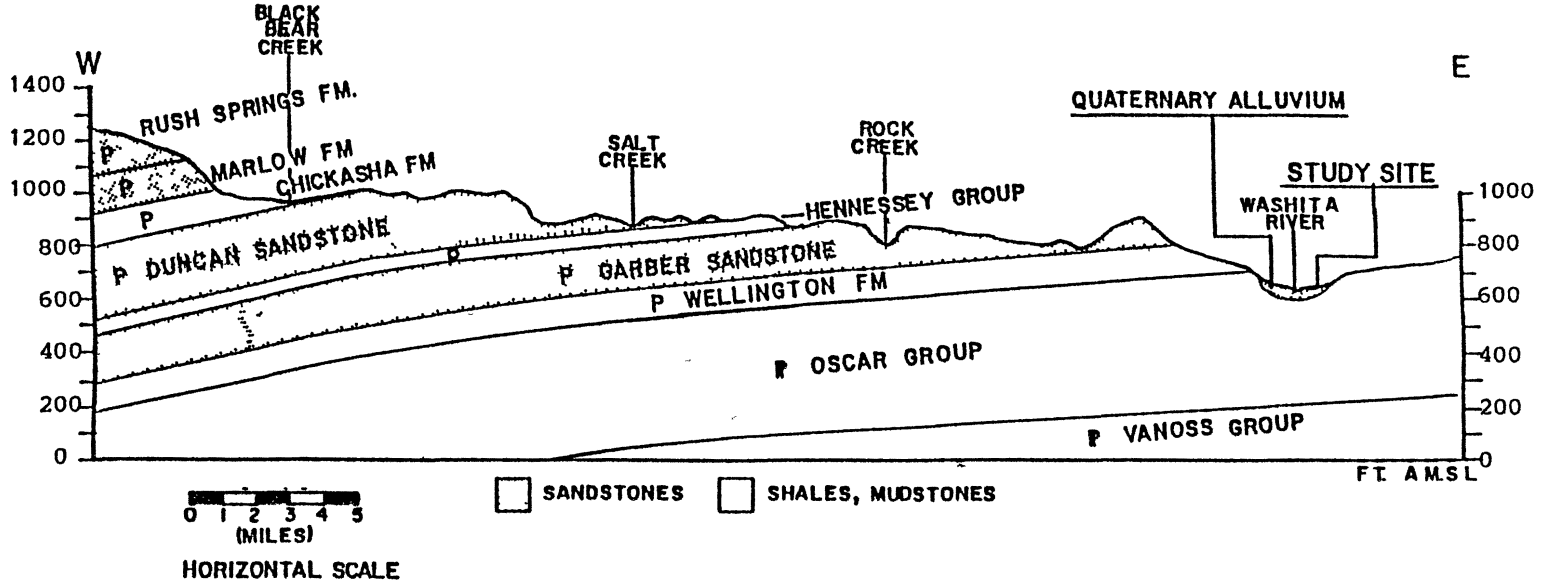


Figure 13. Generalized regional cross section

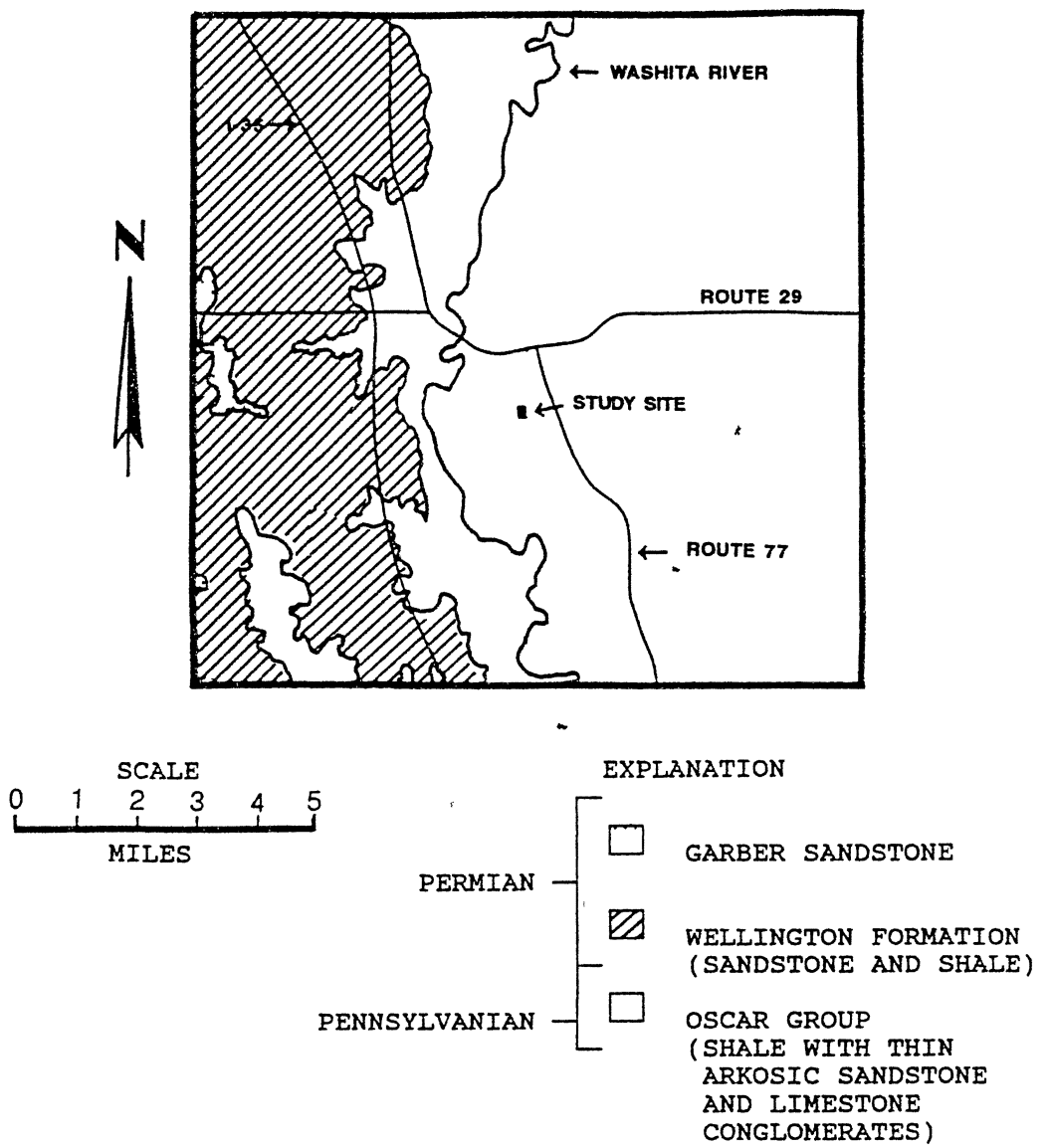


Figure 14. Map of bedrock geology in the Study site area (modified after Hart, 1974)

The Oscar Group is the uppermost bedrock formation in the subject site area. This Group consists mostly of shales with thin beds of arkosic sandstones and conglomerates near the Arbuckle Mountains. The unit is approximately 500 feet thick in the site area, occurring at a depth of 25 to 30 feet in subcrop beneath the alluvial deposits (Hart, 1974).

Underlying the Oscar Group is the Vanoss Formation, consisting mostly of marine shales, arkosic sandstone, and limestone conglomerates. This formation is approximately 900 feet thick in the area, occurring at a depth of approximately 550 feet (Hart, 1974).

The upper-Pennsylvanian Ada Formation lies beneath the Vanoss at a depth of approximately 1,450 feet. The Ada Formation comprises mostly shales, bituminous sandstones, and limestone conglomerates. This formation is approximately 1400 feet thick in the area and lies unconformably upon the Vamoosa Formation (Hart, 1974).

The upper-Pennsylvanian Vamoosa formation comprises mostly shale, sandstone, and chert conglomerate, subdivided into 12 members, each with coarse clastics at the base, overlain by shale. This unit is approximately 1000 feet thick in the area and occurs at a depth of approximately 2850 feet (Hart, 1974).

The youngest sediments at the subject site area are alluvial and terrace deposits of Quaternary age, lying unconformably on the Oscar shales. The alluvial deposits

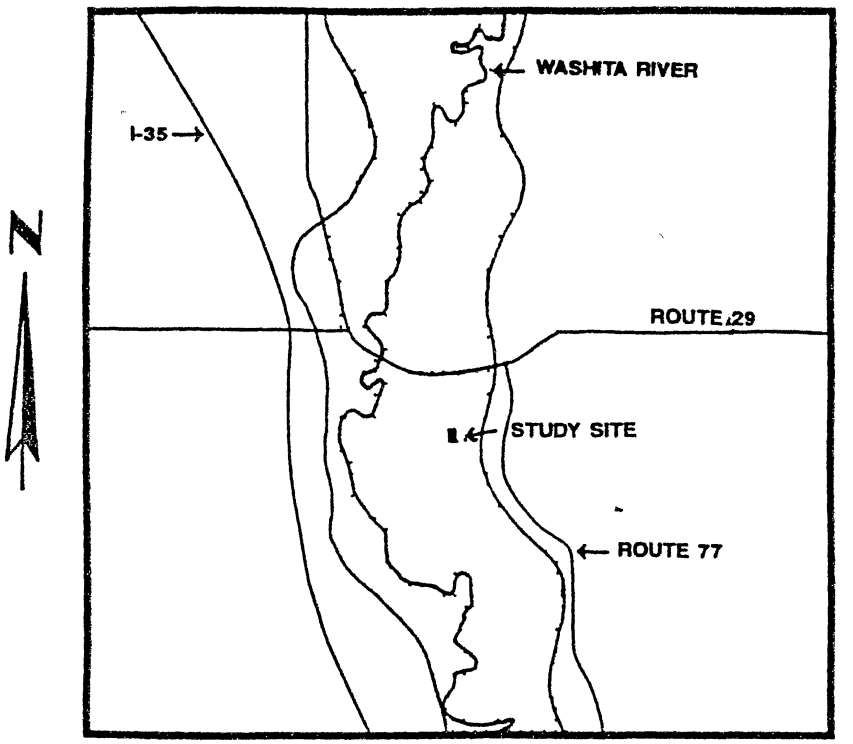
occur along the flood plain of the present day Washita River, consisting mostly of gravels, sands, silts, and clays that were deposited by the River. These deposits are approximately 30 feet thick in the area, increasing in thickness westward to approximately 85 feet near the river, and thinning eastward (Hart, 1974).

There are also small remnant terrace deposits which occur above the present day flood plain of the Washita River. These deposits also consist of gravel, sand, silt, and clay and may reach thicknesses of 60 feet in the area. A map showing the extent of the Quaternary alluvial and terrace deposits in the area is shown in Figure 15 (after Hart, 1974).

Regional Hydrogeology

The alluvial deposits along the Washita River are an important source of ground water in the area. These deposits reach thicknesses of up to 100 feet and yield up to 1200 gallons per minute (gpm). The ground water is of the calcium-magnesium bicarbonate type and contains dissolved solids of 500 to 1000 mg/1; generally fair to good quality water. The alluvial deposits along the major tributaries of the Washita River are generally too thin or too fine grained for water supply development (Hart, 1974).

Recharge to the alluvium occurs mainly where clays are minimal or absent and permeable sands outcrop at the surface. Ground water movement in the alluvial deposits is



SCALE

0 1 2 3 4 5

MILES

EXPLANATION

ALLUVIAL and TERRACE DEPOSITS (SAND, SILT and CLAY)

BEDROCK and ASSOCIATED SOILS

(Modified after Hart, 1974)

Figure 15. Map showing extent of alluvial and terrace deposits in the study site area

generally toward the present day Washita River, which is the regional discharge point for this aquifer. Discharge from this aquifer may also occur from pumpage of wells, evapotranspiration, leakage between stratigraphic horizons, and discharge to major tributaries of the Washita River. Ground water flow rates in this aquifer are estimated at from 10 feet per year to more than 100 feet per year in the thicker and more permeable deposits (Hart, 1974).

The underlying bedrock in the area typically yields only 1 to 2 gpm to drilled wells; enough water for minimum domestic needs only. The quality of the ground water varies from good to saline. Typically the deeper the well, the poorer the quality of water. Ground water typically moves downdip in these formations at rates of 1 to 10 feet/year. These formations are recharged in the areas of outcrop, although recharge is small due to the low permeability of the shales. The depth to the base of the fresh ground water (<1000 TDS) occurs between depths of 500 to 1000 feet in this area. This is within the Oscar Group or the Vanoss Group (Hart, 1974).

Site Hydrogeology

The bulk fuel loading facility is underlain by alluvial sediments deposited in the present-day flood plain of the Washita River. Test borings at the facility indicate that the alluvial clay, sand and gravel deposits that underlie the Facility are continuous over the site. This aquifer

ranges in thickness from 20 to 25 feet and is underlain by a low permeability clay. The ground water flow system of this stratigraphic unit has been investigated by installing several ground water monitoring wells completed to depths ranging from 15 to 75 feet below ground level. Lithology logs for these wells are presented in Appendix A. These logs were used to construct north to south and east to west hydrogeologic cross-sections of the area, presented as Figures 16 and 17. Figure 18 shows the location of the cross section lines. The basal clay was penetrated in three borings at the site: the elevations at these three locations were used to construct Figure 19, which illustrates the elevation of the top of the basal clay unit. Figure 20 is a map of depth to water table (or potentiometric surface) dated April 23, 1991: depth to water was corrected for the thickness and density of floating product where necessary. The depth to water table was then used to construct Figure 21, the potentiometric surface elevation map. Basal clay elevation as shown in Figure 19 was subtracted from the potentiometric elevation in each well to construct Figure 22, the saturated thickness map. All monitor well water level information used in this paper is included as Appendix B. Figure 21 shows the that ground water gradient is in the northwesterly direction, generally towards the Washita River. (Some of the well logs used to construct the maps and cross-sections were recorded before this thesis study

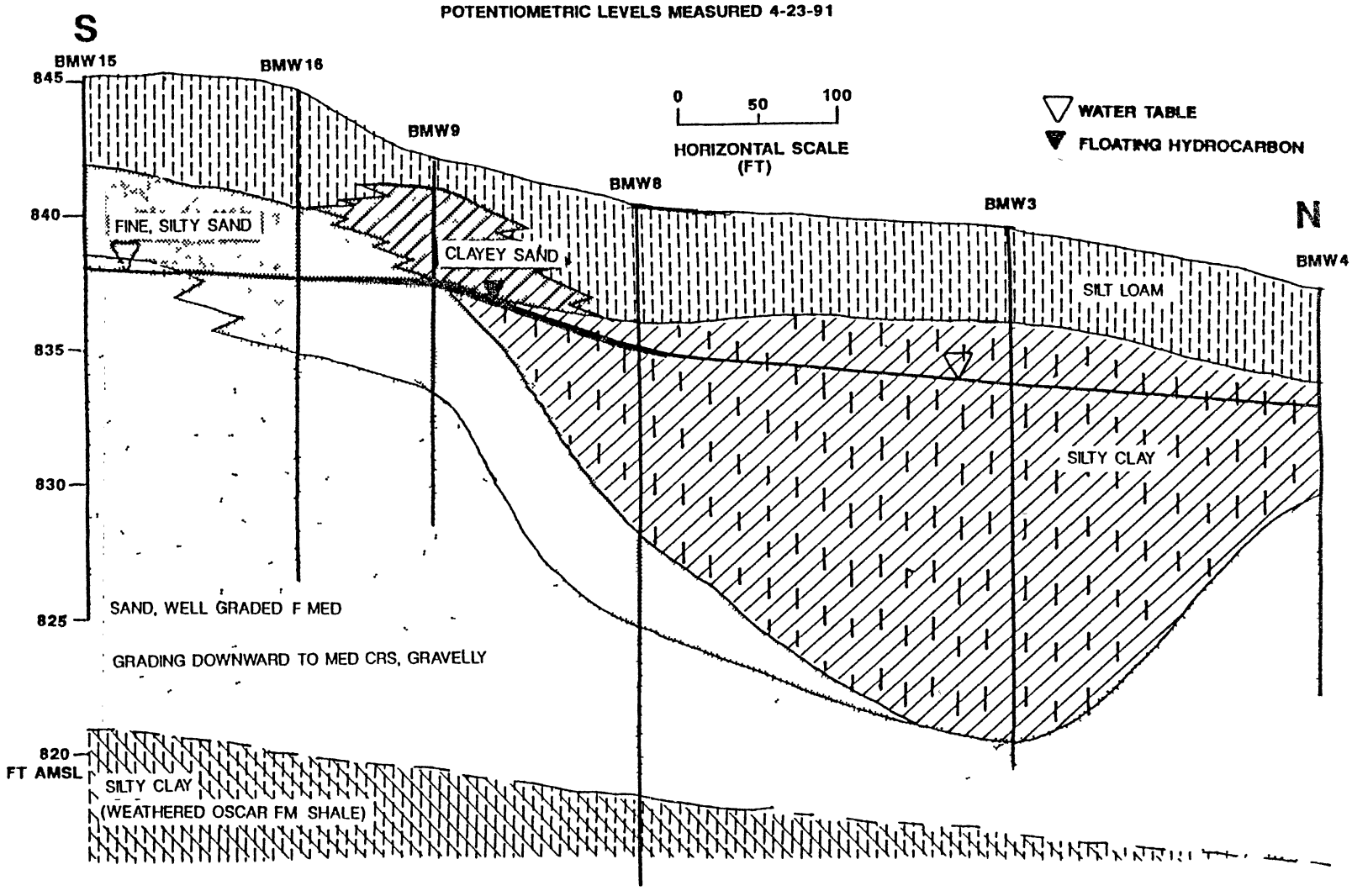


Figure 16. North-south hydrogeologic cross section

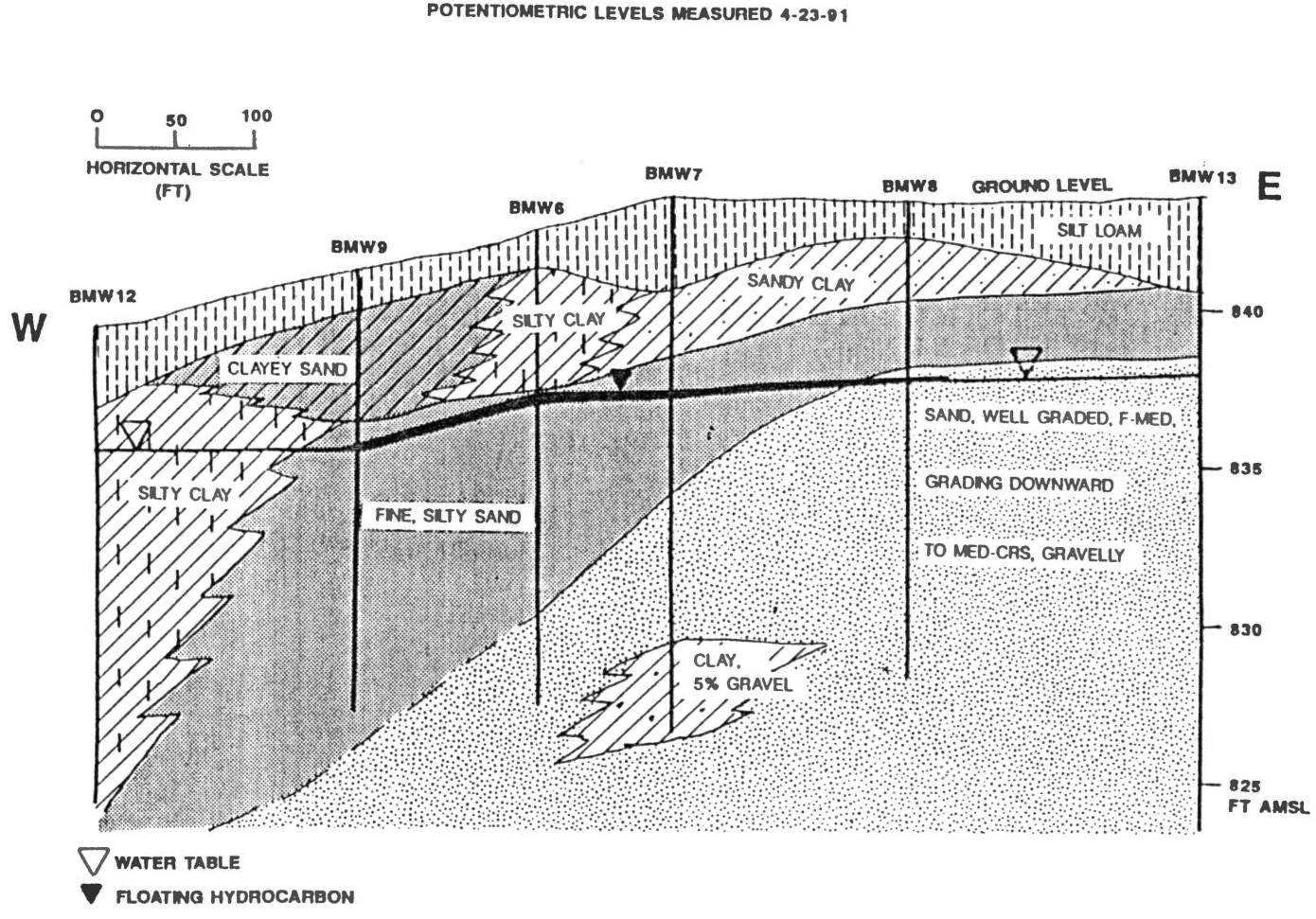


Figure 17. East-west hydrogeologic cross-section

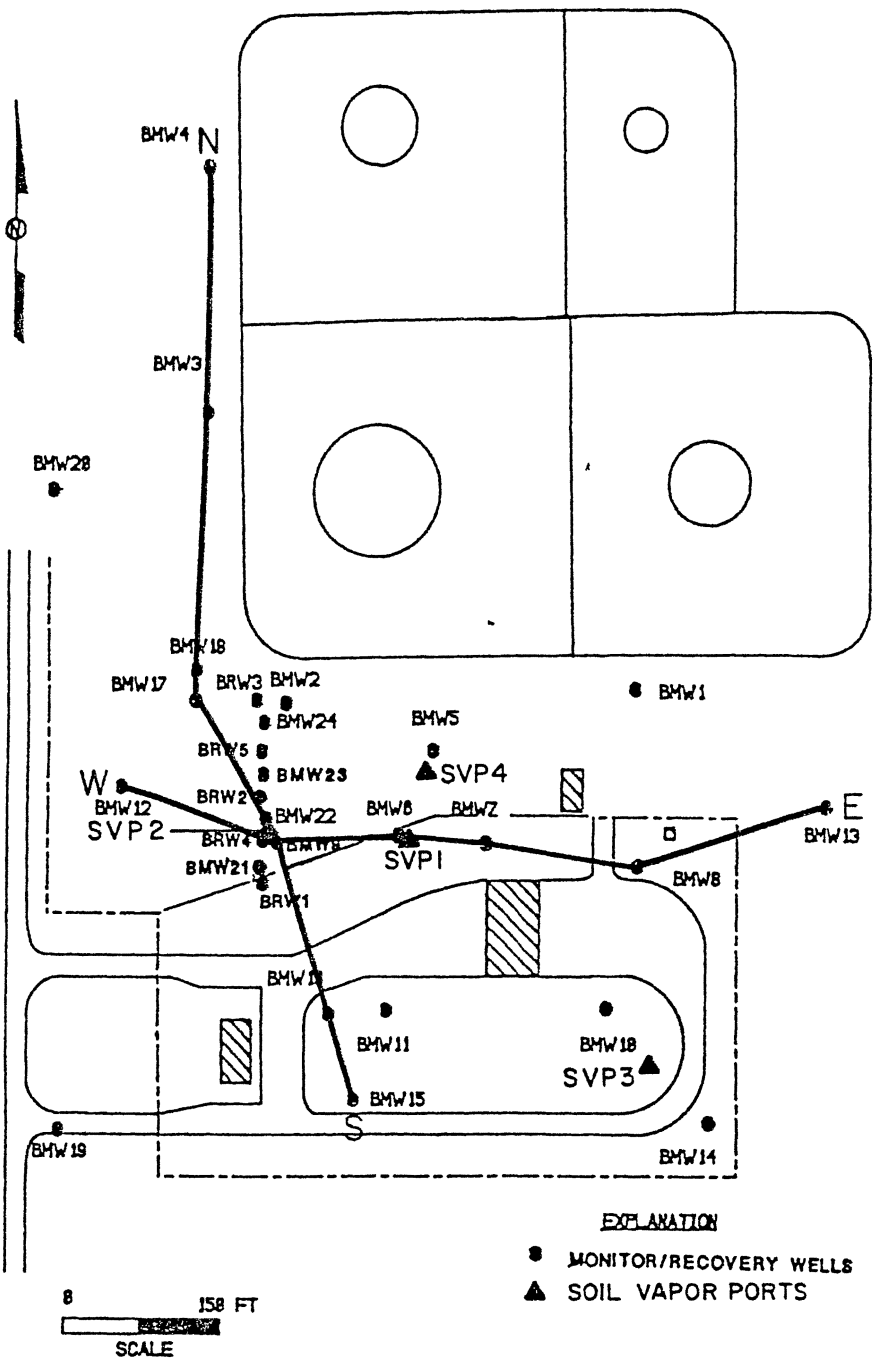


Figure 18. Cross section line location map

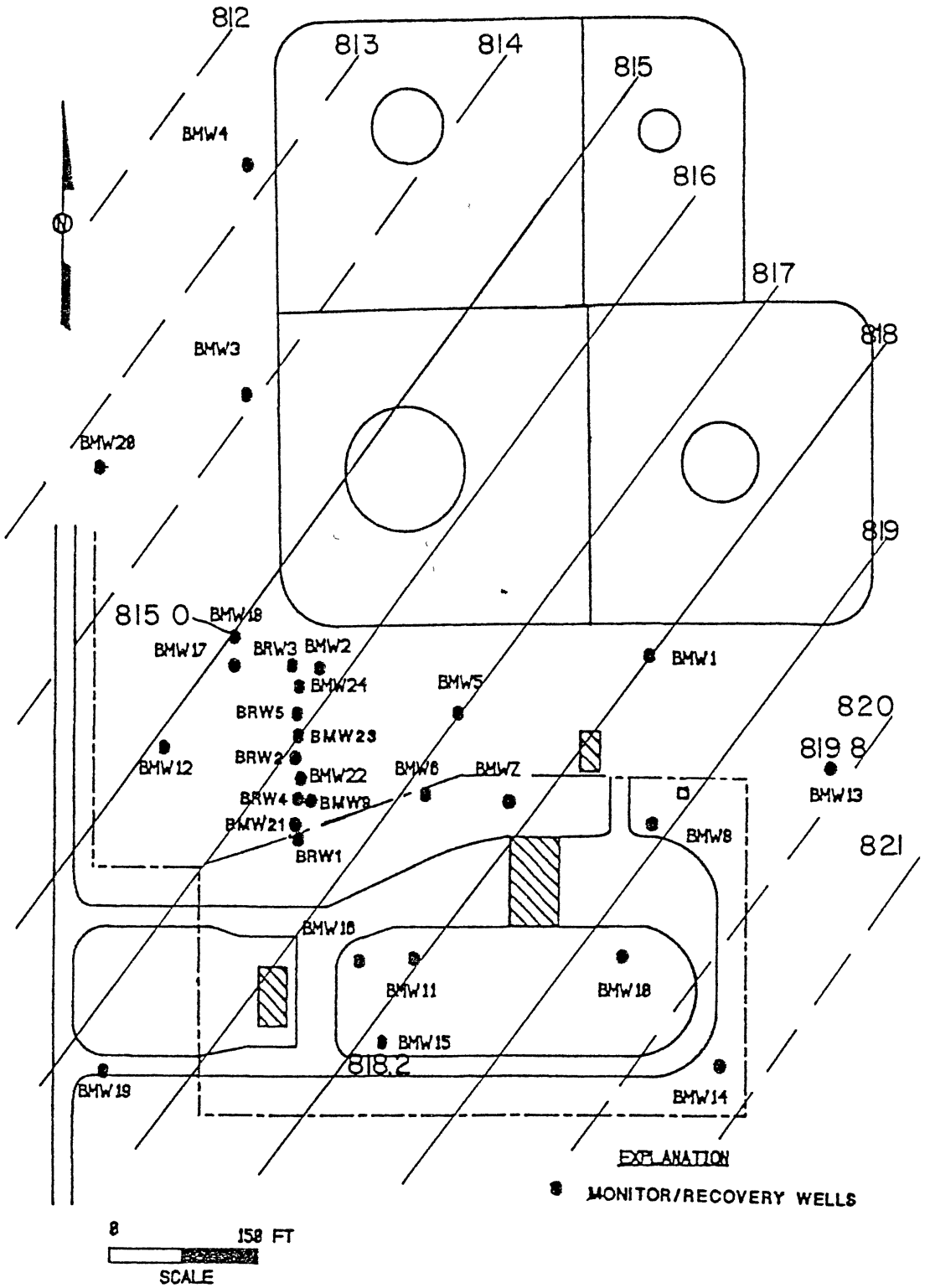


Figure 19. Elevation of top of basal clay confining unit

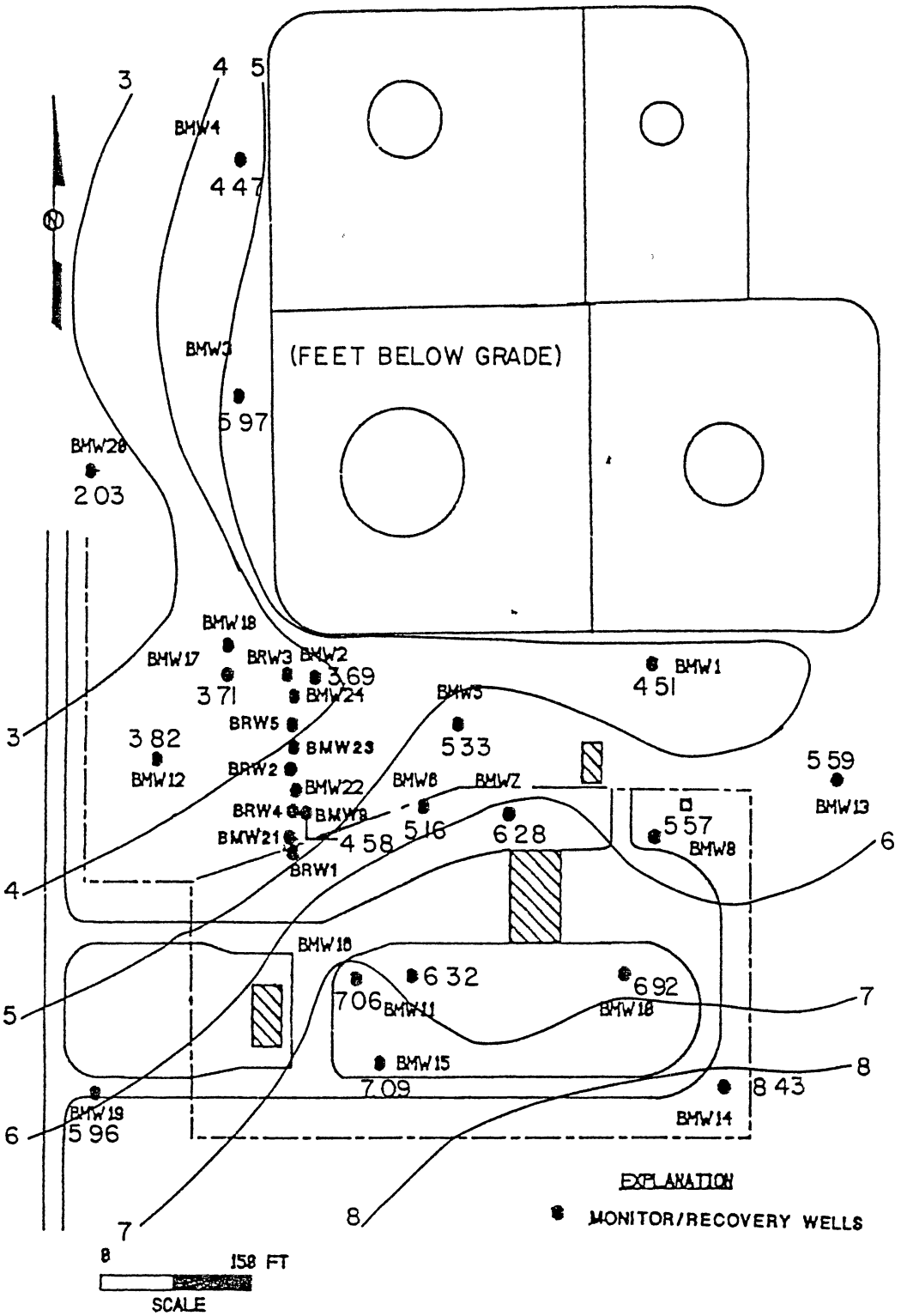


Figure 20. Depth to water table, 4/23/91

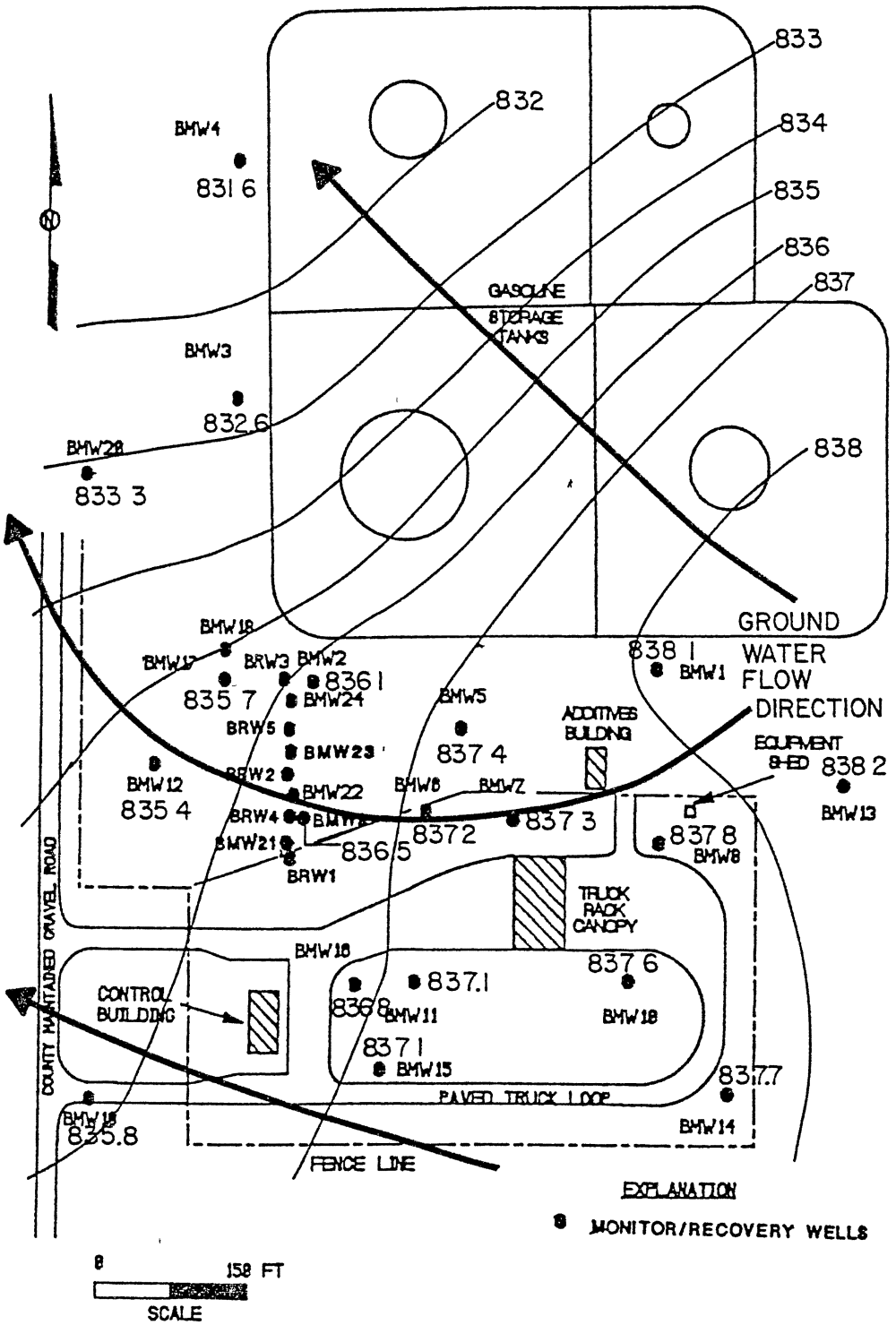


Figure 21. Potentiometric surface elevation map, 4/23/91

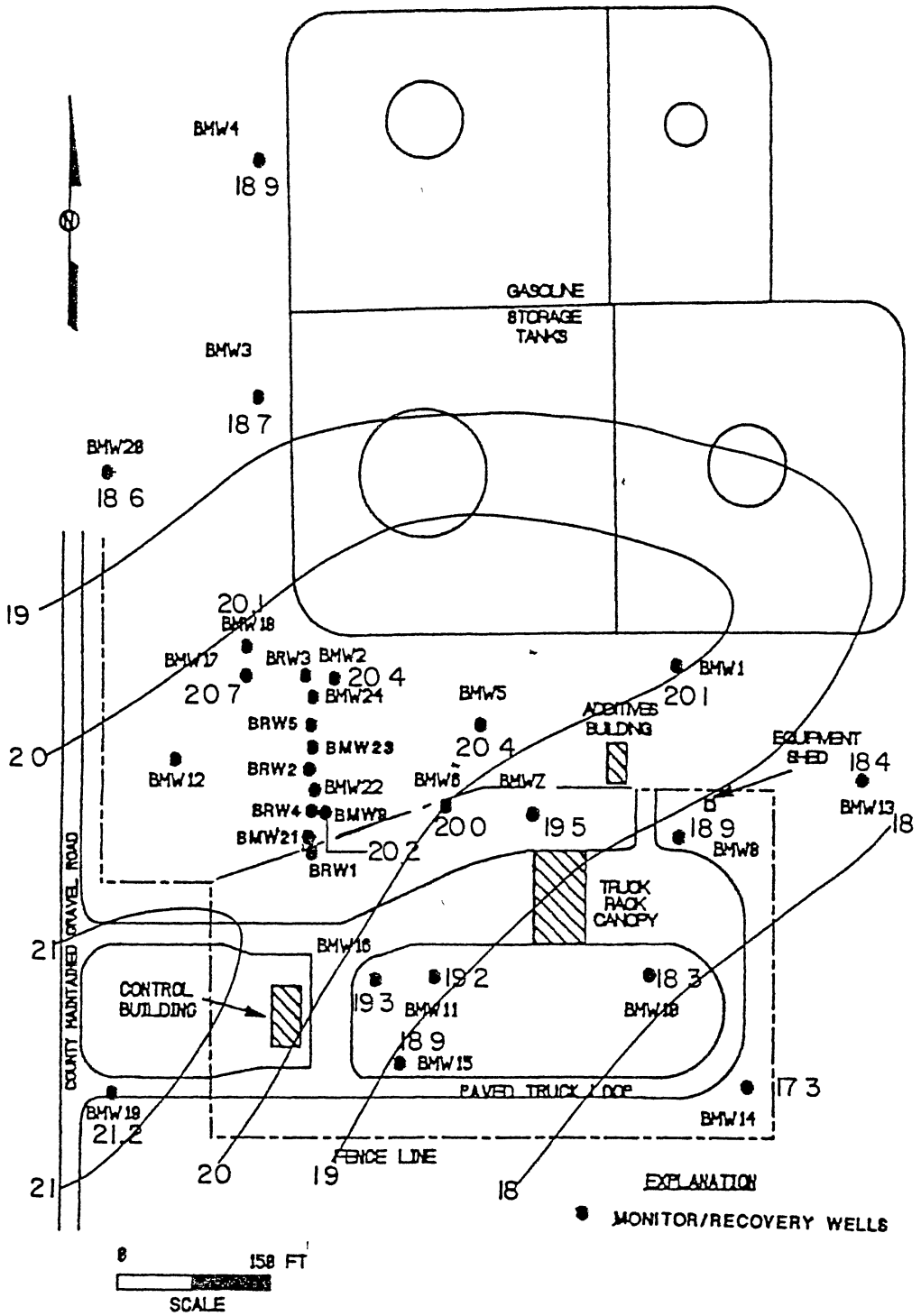


Figure 22. Alluvial aquifer saturated thickness, 4/23/91

was commenced, and by people other than this writer, for use in reports to State authorities).

Aquifer tests were conducted on wells BRW1 and BRW3, which penetrate the entire saturated thickness of the Alluvial Aquifer. The average value for transmissivities determined from these aquifer tests was 5879 gpd/ft. With an average saturated thickness of 20 feet, the hydraulic conductivity of the alluvium equals 294 gpd/ft^2, or 39.3 ft/day. The storage coefficient was estimated to be 0.1 for this formation.

Based upon the hydraulic properties of the alluvial deposits, the maximum gradient (obtained from the potentiometric map presented in Figure 21) and choosing effective porosity of 0.20, the maximum ground water flow velocity can be calculated through the use of the following equation based upon Darcy's law:

$$V = \frac{K_h I}{O}$$

Where V = average ground water velocity

K_h = average horizontal hydraulic conductivity, feet/day

I = hydraulic gradient, dimensionless; and

O = effective porosity, dimensionless.

The following values are used to calculate ground water velocity for the site: K_h = 39.3 feet/day

I = 0.0133 feet/foot

O = 0.20.

These values yield a maximum (seepage) ground water velocity of 2.61 feet per day. The average, or Darcyan velocity, which is not corrected for porosity, equals 0.52 feet per day based on the above stated values.

Figure 23 is a hydrograph of two wells in the study area, including monthly potentiometric surface elevations and precipitation data, for March, 1989 through May 1991. Well BMW10 was the furthest up-gradient and BMW4 the furthest down-gradient well during the time the data was recorded (more up-gradient wells were completed in April, 1990, but were not included in this graph due to the lack of early data for these wells). This hydrograph shows that the alluvial aquifer in this area is quite responsive to precipitation, reacting within the same month to recharge events and discharging at a fairly rapid pace. May, 1990 was the record water table high far data recorded at this site, occurring after 4 consecutive months of higher than average rainfall (during March and April rainfall exceeded the average by almost 8 inches for each month).

The grain size of the alluvial sediments changes significantly across the study site area, as illustrated by figures 16 and 17, hydrogeologic cross sections. This variation in grain size apparently has a marked effect on ground water flow across the area, as discussed later in this paper.

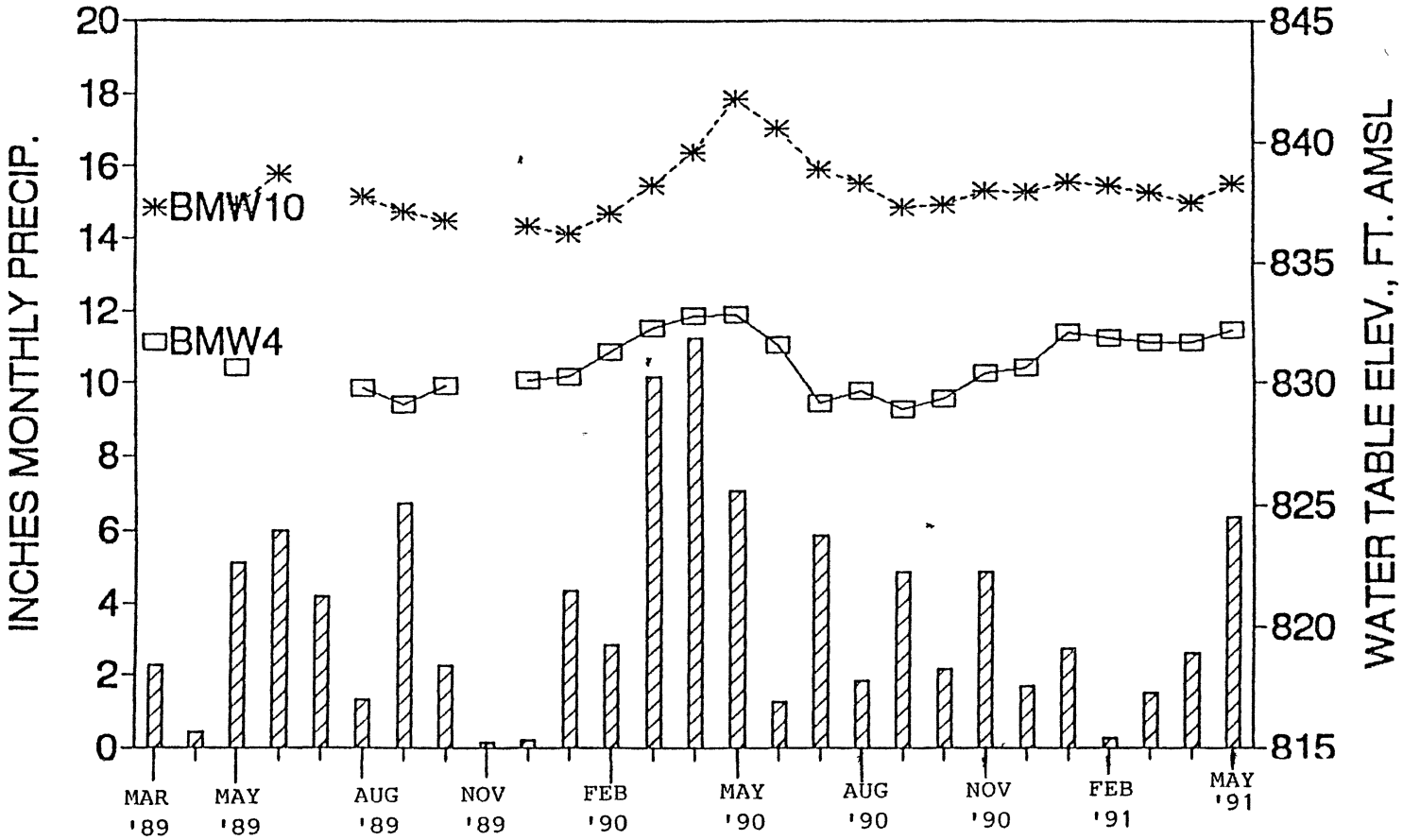


Figure 23. Hydrograph of up-gradient and down-gradient wells at study site, March 1989 to May 1991

Soils Description

Three distinct soil series are recognized at the study site which are classified as Teller loam, 0 to 1 percent slopes, Teller loam, 1 to 3 percent slopes, and Teller fine sandy loam, 2 to 5 percent slopes. Figure 24 depicts the areal extent of each soil type or mapping unit for these series found at the site, as determined by the United States Department of Agriculture Soil Conservation Service (USDA SCS). The Teller series is described as follows by the USDA SCS:

> "The Teller series consists of deep, well drained, moderately permeable, nearly level to sloping soils on broad flats of high stream terraces. These soils formed in material weathered from loamy alluvial sediments under a cover of tall grasses. Slopes range from 0 to 8 percent. The Teller series is a member of the fine-loamy, mixed, thermic family of Udic Argiustolls.
>
> Teller soils are associated with the Norge and Vanoss soils. Norge soils are on higher lying convex ridges and have a fine-silty control section. The Vanoss soils are in slightly lower positions and have a fine-silty control section.
>
> Typical pedon of Teller loam, 0 to 1 percent slopes, 1,800 feet west and 50 feet south of the northeast corner of section 9, T. 2 N., R 1 E.

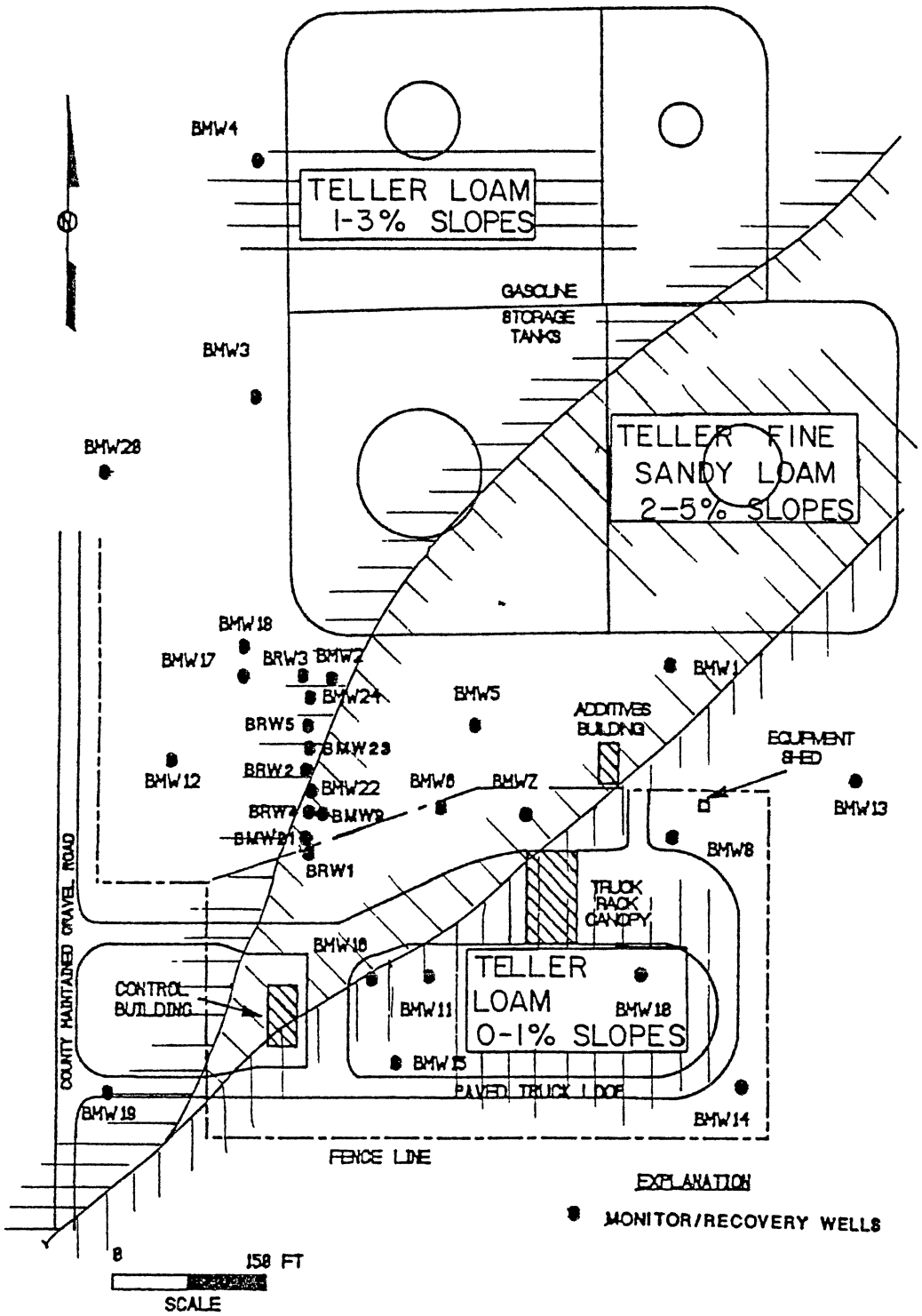


Figure 24. Soil types in the study area, after USDA SCS

A1 - 0 to 12 inches; dark brown (7.5YR 4/2) loam, dark brown (7.5YR 3/2) moist; moderate medium granular structure; slightly hard, very friable; many fine roots; medium acid; gradual smooth boundary.

B1 - 12 to 18 inches; dark brown (7.5TR 4/4) loam, dark brown (7.5YR 3/4) moist; weak medium subangular blocky structure; slightly hard, very friable; many fine roots; many pores; medium acid; gradual smooth boundary.

B2t - 18 to 40 inches; yellowish red (5YR 4/6) clay loam, yellowish red (5YR 3/6) moist; weak medium subangular blocky structure; hard; firm, common fine roots; common pores; continuous clay film on faces of peds; medium acid; gradual smooth boundary.

B3 - 40 to 60 inches; yellowish red (YR5/6) fine sandy loam, yellowish red (5YR 4/6) moist; weak coarse prismatic structure; hard, friable; few fine roots; medium acid; gradual smooth boundary.

C - 60 to 75 inches; reddish yellow (5YR 6/6) fine sandy loam, yellowish red (5YR 5/6) moist; massive, slightly hard, friable; slightly acid.

Solum thicknesses range from 50 to more than 72 inches. The A horizon has a hue of 5YR to 7.5YR, value of 4 or 5, and chroma of 2 or 3. Texture is loam or fine sandy loam. Reaction ranges from medium acid to neutral.

The B1 horizon has hue of 5YR to 7.5YR, value of 4 or 5, and chroma of 2 to 4. Texture is loam. Reaction ranges from medium acid to neutral.

The B2t horizon has hue of 2.5YR or 5YR, value of 4 to 6, and chroma of 4 to 8. Texture is clay loam or sandy clay loam. Reaction ranges from medium acid to neutral.

The B3 horizon has hue of 2.5YR to 5YR, value of 4 to 6, and chroma of 4 to 8. Texture is loam or fine sandy loam. Reaction ranges from medium acid to neutral.

The C1 horizon has hue of 5YR to 7.5YR, value of 4 to 6, and chroma of 5 to 8. Texture is loam or fine sandy loam. Reaction ranges from medium acid to neutral. Some pedons are mildly alkaline to moderately alkaline below 70 inches.

The Teller soils in map units in 71, 72 or 73 (Teller fine sandy loam) are taxadjuncts to the Teller series because they do not have mollic colors deep enough to be a mollic epipedon. This difference has little effect on their use, management or behavior."

Tables III and IV, also from the USDA SCS, list the Engineering properties and land use interpretations for Teller Loam Soils.

TABLE III.

Engineering index properties for Teller Loam soils

(from Garvin County Soil Survey)

Map symbol and soil name	Depth	USDA texture	Classification		Fragments > 3 inches	Percentage passing sieve number--				Liquid limit	Plasticity index
			Unified	AASHTO		4	10	40	200		
	In				Pct					Pct	
71---------- Teller	0-5	Fine sandy loam	SM, ML, SM-SC, CL-ML	A-4	0	100	98-100	94-100	36-60	<26	NP-7
	5-50	Sandy clay loam, clay loam	SC, CL	A-6, A-4	0	100	100	90-100	45-85	24-40	8-18
	50-64	Fine sandy loam, very fine sandy loam, loam	SM, SC, ML, CL	A-4	0	100	98-100	94-100	36-85	<30	NP-10
72---------- Teller	0-8	Fine sandy loam	SM, ML, SM-SC, CL-ML	A-4	0	100	98-100	94-100	36-60	<26	NP-7
	8-32	Sandy clay loam, clay loam	SC, CL	A-6, A-4	0	100	100	90-100	45-85	24-40	8-18
	32-70	Fine sandy loam, very fine sandy loam, loam	SM, SC, ML, CL	A-4	0	100	98-100	94-100	36-85	<30	NP-10
73---------- Teller	0-15	Fine sandy loam	SM, ML, SM-SC, CL-ML	A-4	0	100	98-100	94-100	36-60	<26	NP-7
	15-38	Sandy clay loam, clay loam	SC, CL	A-6, A-4	0	100	100	90-100	45-85	24-40	8-18
	38-66	Fine sandy loam, very fine sandy loam, loam	SM, SC, ML, CL	A-4	0	100	98-100	94-100	36-85	<30	NP-10
74---------- Teller	0-18	Loam----------	ML, CL, CL-ML	A-4	0	100	100	94-100	51-85	<30	NP-10
	18-40	Sandy clay loam, clay loam	SC, CL	A-6, A-4	0	100	100	90-100	45-85	24-40	8-18
	40-75	Fine sandy loam, very fine sandy loam, loam	SM, SC, ML, CL	A-4	0	100	98-100	94-100	36-85	<30	NP-10
75---------- Teller	0-12	Loam----------	ML, CL, CL-ML	A-4	0	100	100	94-100	51-85	<30	NP-10
	12-56	Sandy clay loam, clay loam	SC, CL	A-6, A-4	0	100	100	90-100	45-85	24-40	8-18
	56-66	Fine sandy loam, very fine sandy loam, loam	SM, SC, ML, CL	A-4	0	100	98-100	94-100	36-85	<30	NP-10
76---------- Teller	0-16	Loam----------	ML, CL, CL-ML	A-4	0	100	100	94-100	51-85	<30	NP-10
	16-52	Sandy clay loam, clay loam	SC, CL	A-6, A-4	0	100	100	90-100	45-85	24-40	8-18
	52-70	Fine sandy loam, very fine sandy loam, loam	SM, SC, ML, CL	A-4	0	100	98-100	94-100	36-85	<30	NP-10
78* Teller----------	0-16	Loam----------	ML, CL, CL-ML	A-4	0	100	100	94-100	51-85	<30	NP-10
	16-52	Sandy clay loam, clay loam	SC, CL	A-6, A-4	0	100	100	90-100	45-85	24-40	8-18
	52-70	Fine sandy loam, very fine sandy loam, loam	SM, SC, ML, CL	A-4	0	100	98-100	94-100	36-85	<30	NP-10

TABLE IV.

Land use interpretations for Teller Loam soils, from USDA SCS

SOIL SURVEY INTERPRETATIONS

TeA TELLER LOAM, 0-1 PERCENT SLOPES

THIS IS A DEEP, WELL DRAINED SOIL ON UPLANDS THAT TAKES WATER WELL. IN A REPRESENTATIVE PROFILE THE PLOW LAYER TO 8 INCHES IS A BROWN LOAM. THE REMAINDER OF THE SURFACE LAYER TO 14 INCHES IS A REDDISH BROWN LOAM. THE UPPER PART OF THE SUBSOIL TO 45 INCHES IS A REDDISH BROWN SANDY CLAY LOAM. THE MIDDLE PART OF THE SUBSOIL TO 56 INCHES IS A YELLOWISH RED SANDY CLAY LOAM. THE UNDERLYING MATERIAL TO 66 INCHES IS A RED FINE SANDY LOAM.

ESTIMATED SOIL PROPERTIES

DEPTH (IN)	USDA TEXTURE	UNIFIED	AASHO	FRACT <3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-14	FSL, VFSL, L	SM, SC, ML, CL	A-4	0	100	100	94-100	36-85	<30	4-10
14-56	SCL, CL	SC, CL	A-6, A-4	0	100	100	90-100	85-85	24-40	7-20
56-66	FSL, VFSL, L	SM, SC, ML, CL	A-4, A-6	0	100	100	94-100	85-85	20-34	3-13

DEPTH (IN)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK SWELL POTENTIAL	CORROSIVITY STEEL	CORROSIVITY CONCRETE	EROSION FACTORS K	EROSION FACTORS T	WIND EROD GROUP
0-14	2.0-6.0	12- 16	5.6-6.5	-	LOW	LOW	MODERATE	28	5	-
14-56	0.6-2.0	14- 18	5.6-6.5	-	LOW	LOW	MODERATE			
56-66	2.0-6.0	13- 17	5.6-7.3	-	LOW	LOW	MODERATE			

FLOODING FREQUENCY	FLOODING DURATION	FLOODING MONTHS	HIGH WATER TABLE DEPTH (FT)	HIGH WATER TABLE KIND	HIGH WATER TABLE MONTHS	CEMENTED PAN DEPTH (IN)	CEMENTED PAN HARDNESS	BEDROCK DEPTH (IN)	BEDROCK HARDNESS	HYD GRP
NONE			>6			-		>60		B

SANITARY FACILITIES	
SEPTIC TANK ABSORPTION FIELDS	SLIGHT
SEWAGE LAGOON AREAS	SEVERE-PERCS RAPIDLY
SANITARY LANDFILL (TRENCH)	SEVERE-PERCS RAPIDLY
SANITARY LANDFILL (AREA)	SLIGHT
DAILY COVER FOR LANDFILL	GOOD

COMMUNITY DEVELOPMENT	
SHALLOW EXCAVATIONS	SLIGHT
DWELLINGS WITHOUT BASEMENTS	SLIGHT
DWELLINGS WITH BASEMENTS	SLIGHT
SMALL COMMERCIAL BUILDINGS	SLIGHT
LOCAL ROADS AND STREETS	MODERATE-LOW STRENGTH

SOURCE MATERIAL	
ROADFILL	GOOD
SAND	UNSUITED-EXCESS FINES
GRAVEL	UNSUITED-EXCESS FINES
TOPSOIL	GOOD

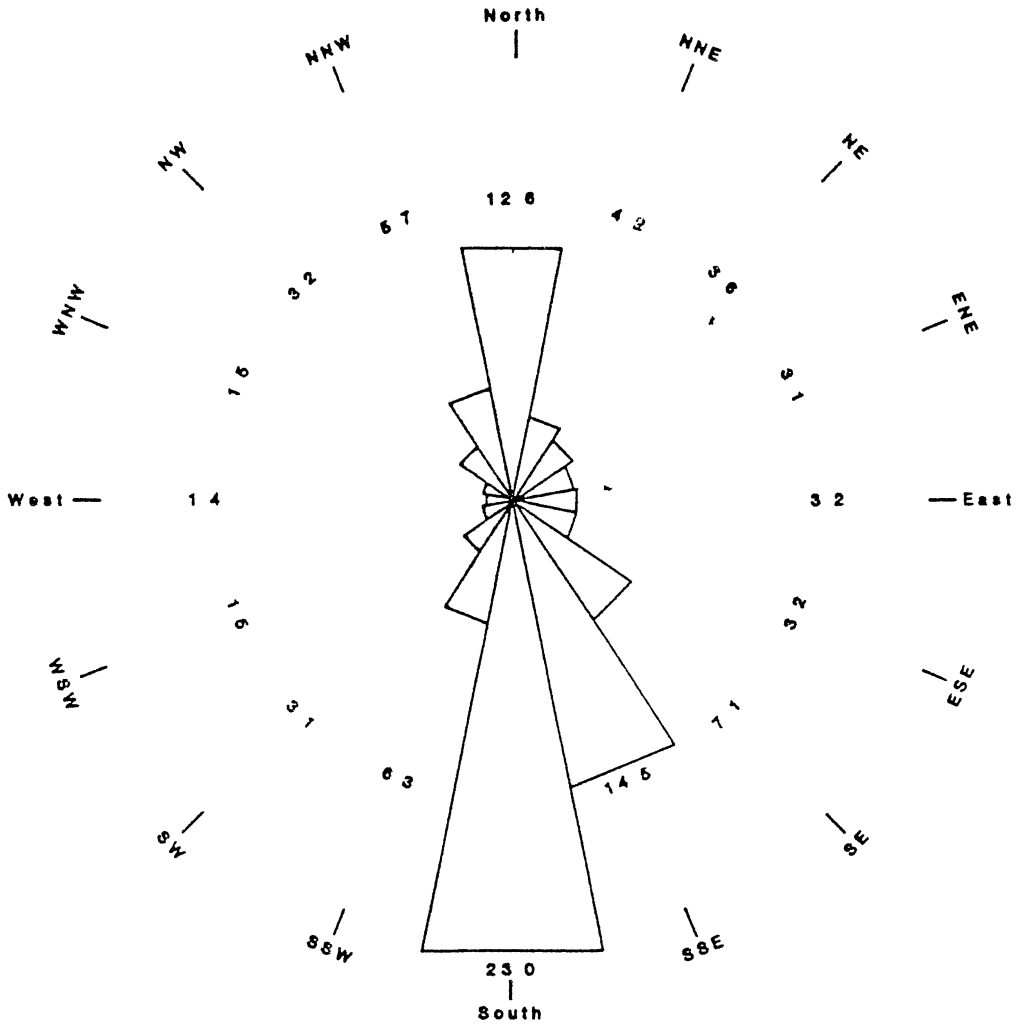
WATER MANAGEMENT	
POND RESERVOIR AREA	SEVERE-PERCS RAPIDLY
EMBANKMENTS DIKES AND LEVEES	MODERATE-UNSTABLE FILL, PIPING
EXCAVATED PONDS AQUIFER FED	SEVERE-NO WATER
DRAINAGE	NOT NEEDED
IRRIGATION	ERODES EASILY
TERRACES AND DIVERSIONS	ERODES EASILY, PIPING
GRASSED WATERWAYS	ERODES EASILY

Climate

The climate of this area is dry subhumid continental. The continental effect produces pronounced daily and seasonal temperature changes and considerable variations in seasonal and annual precipitation. The summer season is typically long and hot, with high temperatures ranging in the high nineties and, on occasion, the hundreds. The winter is relatively mild and short, with temperatures commonly dropping below freezing. January is generally the coldest month of the year.

The climate of the area is dominated by continental controls characteristic of the Great Plains region, punctuated by occasional warm, moist air from the Gulf of Mexico. Prevailing winds are out of the south, as illustrated by Figure 25. Wind velocities are relatively uniform, being greatest out of the south-southwest and north-northwest. The mean annual wind speed is approximately 10.0 knots. or 11.0 miles per hour (Figure 26).

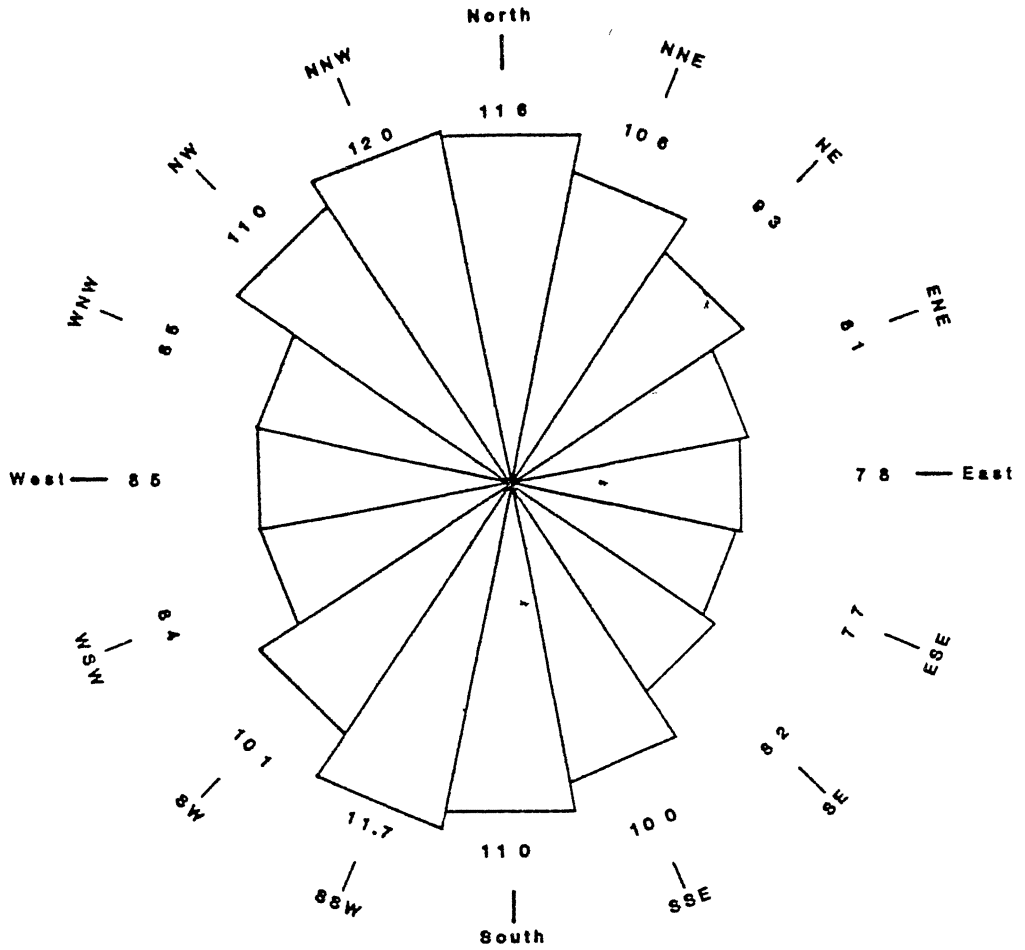
The mean annual calendar year precipitation for the Pauls Valley-Wynnewood area, based upon the 30-year period extending from 1958 through 1987, is 35.34 inches. Annual precipitation during this period ranged from a minimum of 19.02 inches (1963) to a maximum of 50.25 inches (1985). Snowfall averages less than 10 inches per year and seldom remains on the ground for any extended period. The 30-year



(PERCENT OF TIME) OKLAHOMA CITY, OKLAHOMA

SOURCE TABLE 11A (ANNUAL), AIRPORT CLIMATOLOGICAL SUMMARY, WILL ROGERS WORLD AIRPORT, NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

Figure 25. Wind Rose showing mean annual direction



OKLAHOMA CITY, OKLAHOMA

SOURCE TABLE 11A (ANNUAL), AIRPORT CLIMATOLOGICAL SUMMARY, WILL ROGERS WORLD AIRPORT, NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

Figure 26. Wind rose showing mean annual wind speed, knots

Table V.
30-year precipitation data for Pauls Valley, Oklahoma, 1958-1987

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
58	2.28	1.47	2.71	2.56	4.08	3.59	3.31	1.44	0.86	0.20	2.17	0.99	25.68
59	0.39	1.30	1.14	2.62	4.53	1.72	2.77	2.73	6.72	5.30	1.84	2.96	34.03
60	2.11	2.10	1.35	2.61	8.99	1.15	4.60	3.43	3.71	7.36	0.17	4.73	42.33
61	0.13	1.60	4.68	0.60	4.25	4.19	3.46	0.99	6.57	2.83	3.17	1.21	33.70
62	0.38	1.16	1.48	2.86	2.92	6.88	1.38	0.17	3.42	5.44	2.40	3.12	31.63
63	0.14	0.00	4.33	2.58	1.11	0.75	2.01	2.19	1.28	0.36	2.77	1.47	19.02
64	0.86	1.73	2.89	2.55	6.74	1.74	0.37	6.68	4.01	0.83	6.61	0.86	35.90
65	2.35	1.05	1.25	1.90	4.27	2.78	0.80	3.48	3.65	2.02	0.53	0.54	24.64
66	0.96	1.51	0.74	4.12	0.86	1.36	3.73	4.23	2.50	0.98	1.17	0.94	23.12
67	0.08	0.10	1.22	6.35	6.70	3.24	3.37	0.58	4.18	3.22	0.57	1.47	31.09
68	3.88	1.87	2.59	2.18	7.90	6.22	2.54	3.48	6.38	2.46	5.25	1.56	46.34
69	1.84	3.33	2.83	4.10	3.13	2.81	2.31	3.37	2.59	3.91	0.44	2.86	33.54
70	0.18	1.23	2.01	5.02	2.12	3.78	1.83	1.47	5.99	11.00	1.10	0.45	36.20
71	2.47	1.48	0.45	2.80	3.37	3.14	2.65	1.66	1.94	5.41	0.35	5.20	30.94
72	0.37	1.19	0.48	3.37	4.51	1.43	1.02	2.44	4.30	7.88	3.80	0.72	31.54
73	3.41	1.38	3.98	6.50	4.00	7.11	2.09	0.19	7.24	5.33	5.49	0.56	47.30
74	0.25	1.77	1.61	4.33	3.75	4.66	1.23	7.11	6.74	6.95	1.33	1.23	40.98
75	2.42	3.11	5.45	3.54	9.19	4.93	6.98	1.40	3.75	0.66	2.03	1.59	45.06
76	0.01	0.48	3.23	5.32	3.56	1.21	1.86	2.22	2.28	3.33	0.45	1.73	25.70
77	1.45	1.61	2.95	2.89	13.35	1.91	1.35	4.20	2.14	2.32	1.10	0.19	35.48
78	1.00	2.74	1.99	2.94	8.14	3.96	0.78	0.54	1.37	0.99	3.28	0.74	28.50
79	1.72	0.59	3.10	5.08	3.64	9.20	2.63	2.34	1.10	3.45	4.26	1.75	38.88
80	1.28	1.36	1.27	1.74	9.61	2.10	0.00	0.29	3.68	1.80	1.73	2.30	27.16
81	0.07	2.51	2.85	1.52	6.04	5.51	3.48	2.59	2.36	9.58	2.06	0.55	39.13
82	1.70	1.74	1.85	1.80	14.33	5.09	3.50	0.84	1.19	1.95	4.22	2.78	40.99
83	3.45	0.78	3.15	3.33	7.78	3.14	0.09	3.14	2.71	9.15	1.41	0.61	38.74
84	0.36	1.22	3.00	1.90	1.92	6.35	0.32	1.28	1.60	4.89	2.43	5.78	31.06
85	2.36	4.43	5.34	4.74	2.64	8.19	0.93	2.23	7.77	8.53	2.34	0.73	50.25
86	0.00	1.87	1.83	3.74	10.08	2.43	0.72	2.12	9.32	3.15	4.80	1.59	41.65
87	2.72	4.91	2.83	0.94	12.56	4.06	4.09	1.22	4.74	2.50	3.14	5.81	49.53
MEAN:	1.35	1.72	2.49	3.22	5.87	3.82	2.21	2.33	3.87	4.13	2.41	1.90	35.34

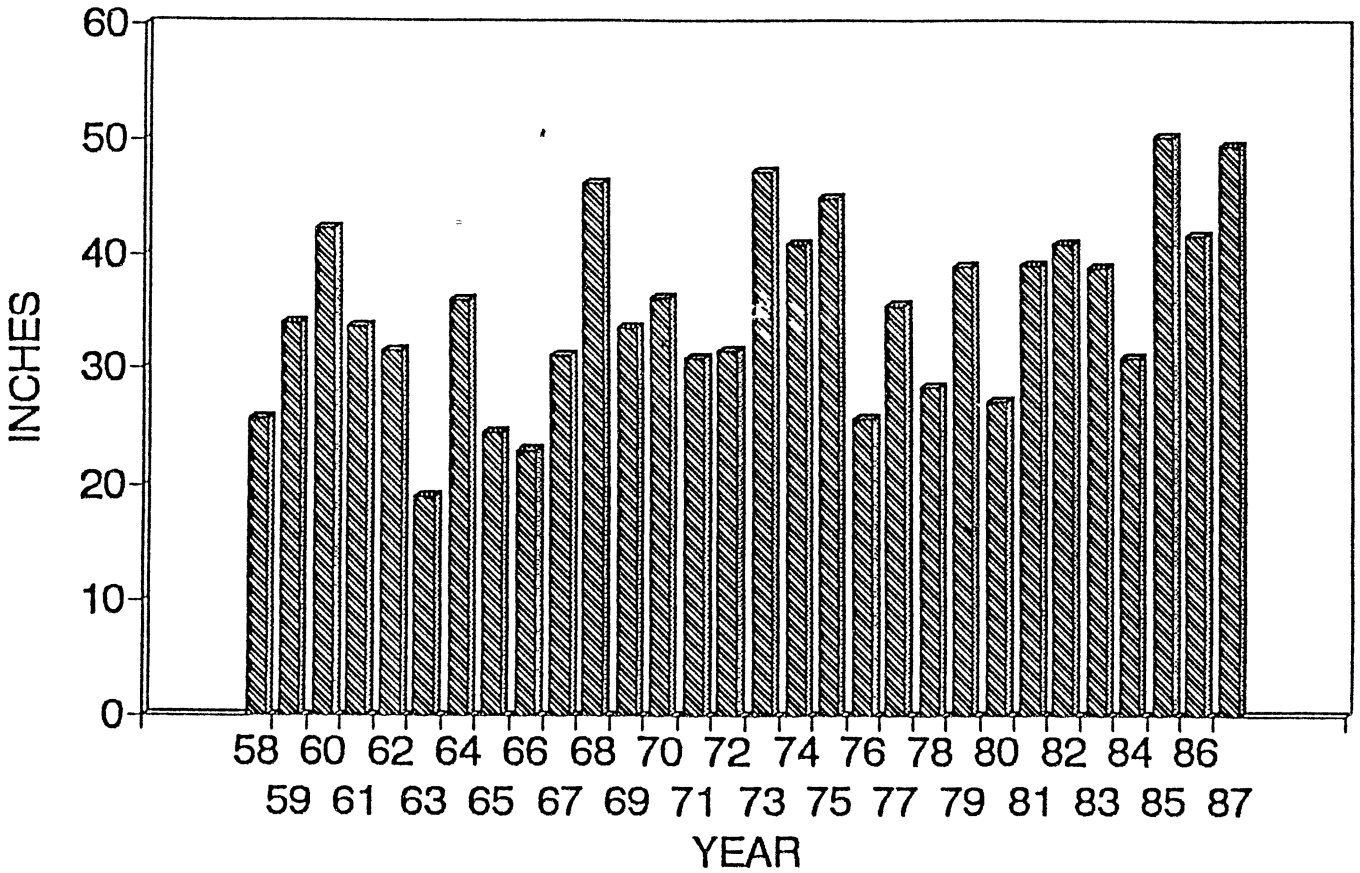


Figure 27. Bar graph showing mean annual precipitation at Pauls Valley, OK, 1958-1987

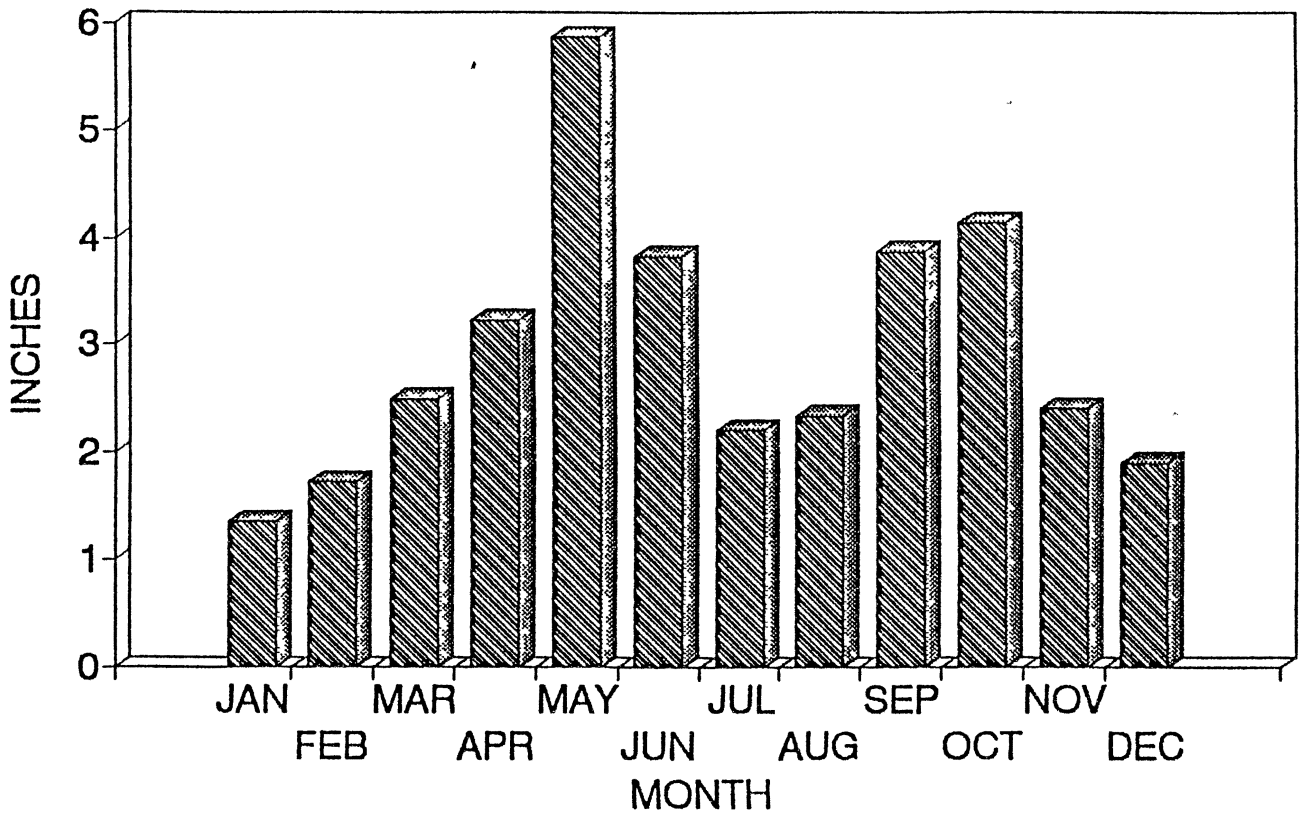


Figure 28. Bar graph showing mean monthly precipitation at Pauls Valley, OK, 1958-1987

calendar precipitation data are presented in Table V and Figure 27. The maximum monthly precipitation recorded for this region was 14.33 inches in May of 1982. Spring and summer have historically been the wettest times of the year, with the winter months being the driest. Summer rainfall comes mainly from showers and thunderstorms. Winter precipitation is generally associated with large scale air mass movements. Figure 28 shows mean monthly precipitation for the 30-year period.

The annual temperatures for the area are relatively uniform. The mean annual temperature, based upon the 30-year calendar year period 1959 through 1987, is 62.2°F.

Annual mean temperatures for this period ranged from a minimum of 50.0°F to a maximum of 74.4°F. Mean monthly temperatures for the 30-year period from 1958 to 1987 are listed in Table VI and illustrated by Figure 29. Climatic data are from the National Oceanic and Atmospheric Administration.

Evapotranspiration

The average annual potential evapotranspiration, as calculated by the "Thornthwaite and Mather" method (Thornthwaite and Mather, 1957), and based on 30-year average climatic data from 1958 to 1987, is approximately 37 inches per year. This exceeds annual average precipitation of 35.34 inches for the same period.

TABLE VI

30-Year Mean Monthly Temperature Data
Pauls Valley, OK

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN	38.5	42.5	52.8	63.2	70.7	78.5	83.4	82.5	74.8	64.0	51.8	42.0	62.2
MAX	50.4	54.7	65.5	75.8	82.4	89.9	95.6	95.2	86.7	77.1	63.8	53.5	74.4
MIN	26.5	30.3	40.0	50.6	58.9	67.1	71.2	69.8	62.9	50.9	39.7	30.6	50.0

(1958-1987)

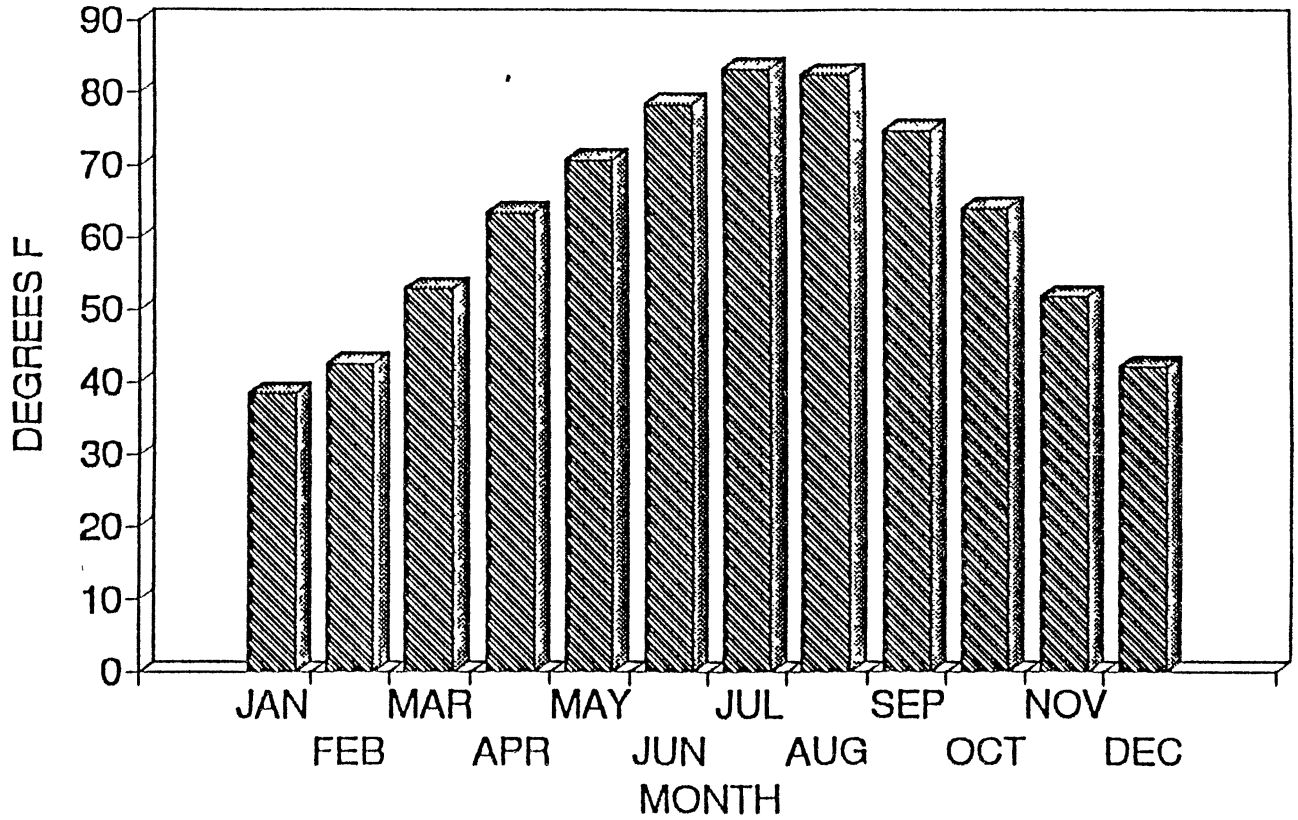


Figure 29. Bar graph showing mean monthly temperature at Pauls Valley, OK, 1958-1987

Surface Water

The major stream system in this part of Oklahoma is the south-flowing Washita River and its tributaries. The subject site lies within its drainage basin. Drainage off the study site is first to the northwest, into a topographic depression (ephemeral stream) at the northwest corner of the site which trends south-southwest (Figure 30). From there surface water flows into Hogg creek which flows into the Washita River.

Suitability of Site for Investigation by Soil Organic Vapor Measurement

Table I (Chapter II) lists parameters affecting movement of organic vapors through soils. Also in Chapter II the ideal source and site characteristics for soil vapor studies are listed. Those characteristics and their relative suitability for measurement of soil organic vapor as an indicator of associated ground water impact by organics are as follows for this site:

SOURCE MATERIAL CHARACTERISTICS (gasoline)

1. Density: approximately 0.75 g/cm^3
2. Viscosity: fairly low, near that of water
3. Volatility: fairly volatile but not extremely
4. Water solubility: low to moderate with a few very soluble constituents
5. Potential for degradation: moderate to high

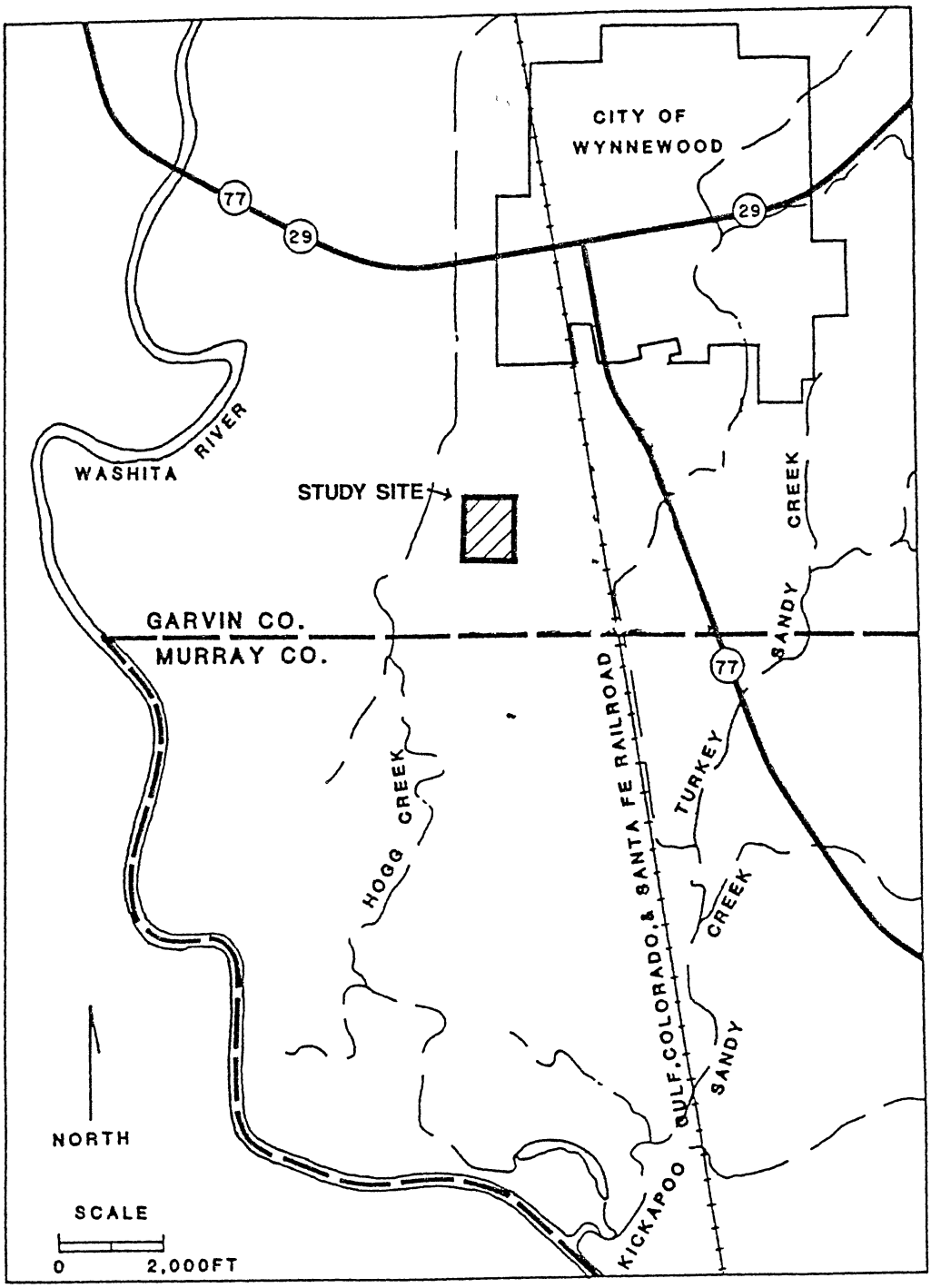


Figure 30. Surface drainage near study site

6. Age of spill: this is by definition a relative parameter - since there are fairly high concentrations of volatiles left in the soil, it is reasonable to refer to the spill at this site as relatively young to medium age.

The characteristics of the source material as listed above are generally very good for the application of soil vapor measurement methods. The hydrogeologic characteristics of the site, however, as listed below, are generally not ideally favorable for soil organic vapor measurement.

SITE CHARACTERISTICS

1. Soil Texture: relatively fine
2. Soil moisture content: moderately high
3. Degree of soil texture anisotropy: moderate to high
4. Depth to ground water: quite shallow
5. Extent of water table fluctuation: high

The relatively fine soil texture and the extent of water table fluctuation, in combination with the shallow ground water depth, are probably the most important characteristics of the site that will negatively affect the measurement of organic vapors in the soil. As discussed in more detail later in this paper, the fine-textured soils at the site made collection of vapor samples difficult, and required utilization of less than optimal methods. The shallow ground water at the site, coupled with relatively

large fluctuations in the water table may have caused hydrocarbons to be "smeared" in soils just below the ground surface; floating liquid-phase hydrocarbons may have been adsorbed onto soil materials. The adsorbed liquid phase could then volatilize from the soil instead of only from the ground water, resulting in higher concentrations of organics in the soil vapor. The soil vapor may also contain a higher percentage of the less volatile components than would be expected if the soil had not been exposed to liquid gasoline.

The study site thus does not have all the ideal requirements for estimation of the concentration and/or constituents of organics in the ground water by measuring organics in soil vapor. Few sites are "ideal", however; this site portrays a "real-world" situation, and while presenting problems, may also provide insight into how to deal with them.

Previous Work at the Site: Source Characterization

In 1986 the facility was expanded; more loading bays were added to accommodate a larger number of trucks. When the footings were dug for the new foundation, free product was discovered in the soil. The source for the product, which was identified as premium unleaded gasoline, was determined to be a defective weld in a pipeline, about four feet below surface. The location of the pipeline leak is

shown in Figure 31, which also shows hydrocarbon thickness in monitoring wells. The leaking gasoline apparently travelled along the more permeable fill material in the pipeline ditch, moving much further in the upgradient direction than would otherwise be expected. After initial measures were taken to recover product from the area immediately around the leak, numerous soil borings were completed to delineate the extent of free product migration. Soils were continuously sampled using a hollow-stem auger-equipped drilling rig, and soil sample headspace was analyzed with a photoionization detector to determine the extent and degree of hydrocarbon impact. Ground water monitoring wells were installed interior to and around the perimeter of the liquid hydrocarbon plume to identify the lateral and vertical extent of liquid-phase hydrocarbon. Ground water interception and product recovery wells were then installed to begin removing the gasoline from the ground water and to prevent impacted ground water from moving further down-gradient. The monitor wells, as shown in Figure 31, provide close definition of liquid hydrocarbon occurrence.

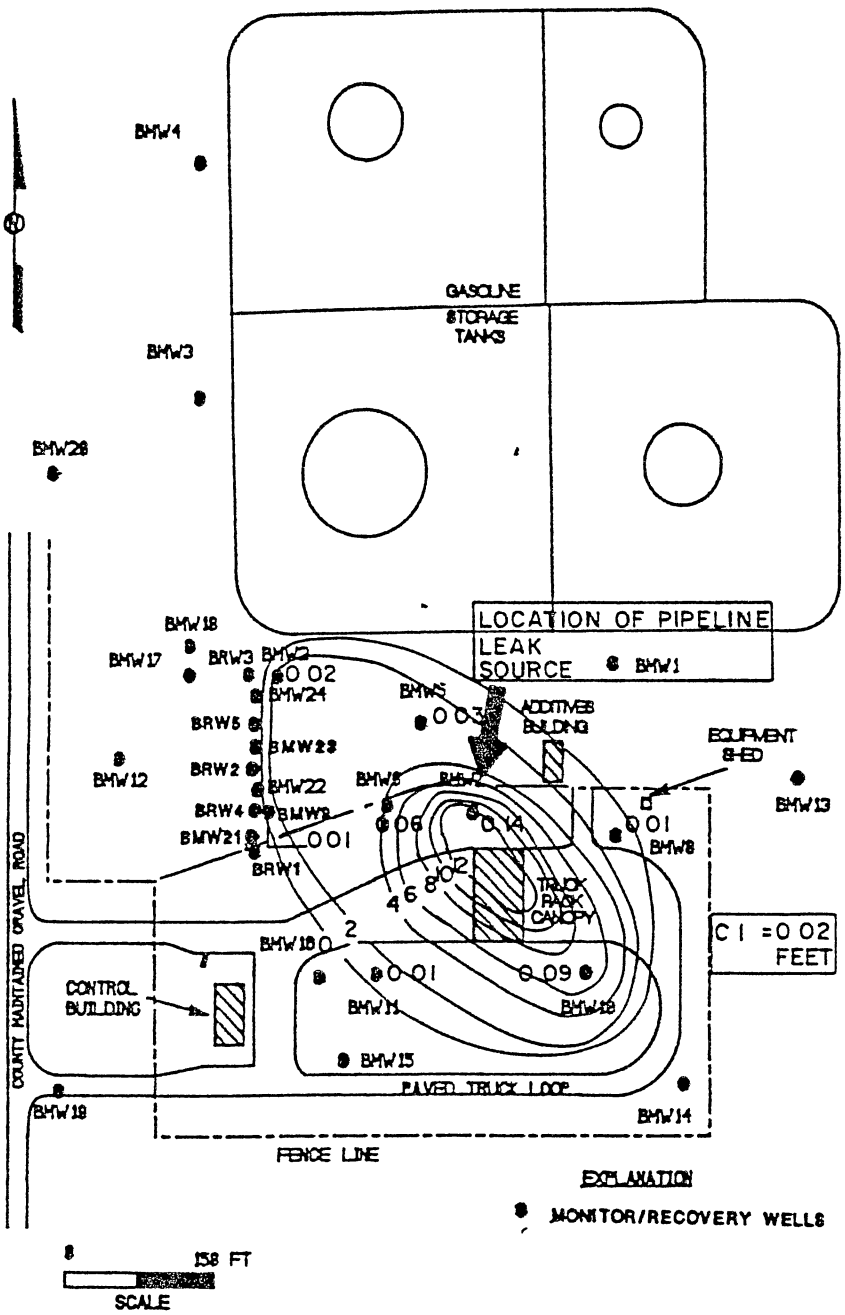


Figure 31. Location of pipeline leak source and thickness of floating hydrocarbon in monitor wells, 4/23/91

CHAPTER IV

EXPERIMENTAL METHODOLOGIES

Selection of Soil Vapor Sampling Methodology

There are numerous methods of collecting soil vapor samples, as discussed in Chapter II. The most widely used is the driven ground probe; the reasons for the prominence of this method are ease of use and the ability to recover a representative sample of soil interstitial vapors. This method was used at the subject site in attempt to conduct a soil vapor survey across the entire study area. Because of the low soil permeability across most of the study area, it was found to be impossible to obtain a soil vapor sample with the available equipment.

Several types of probe tip designs were utilized to attempt to recover a vapor sample. First a fluted, perforated tip without a retractable sleeve was used (Figure 32). The perforations became clogged with almost every insertion of the probe, preventing movement of vapor into the probe. Then a probe with a retractable tip was designed, to circumvent the plugging (Figure 33). This design worked well in coarser grained soils, but in clayey to silty areas this probe tip also failed to allow collection of a vapor sample. The fine grained soils

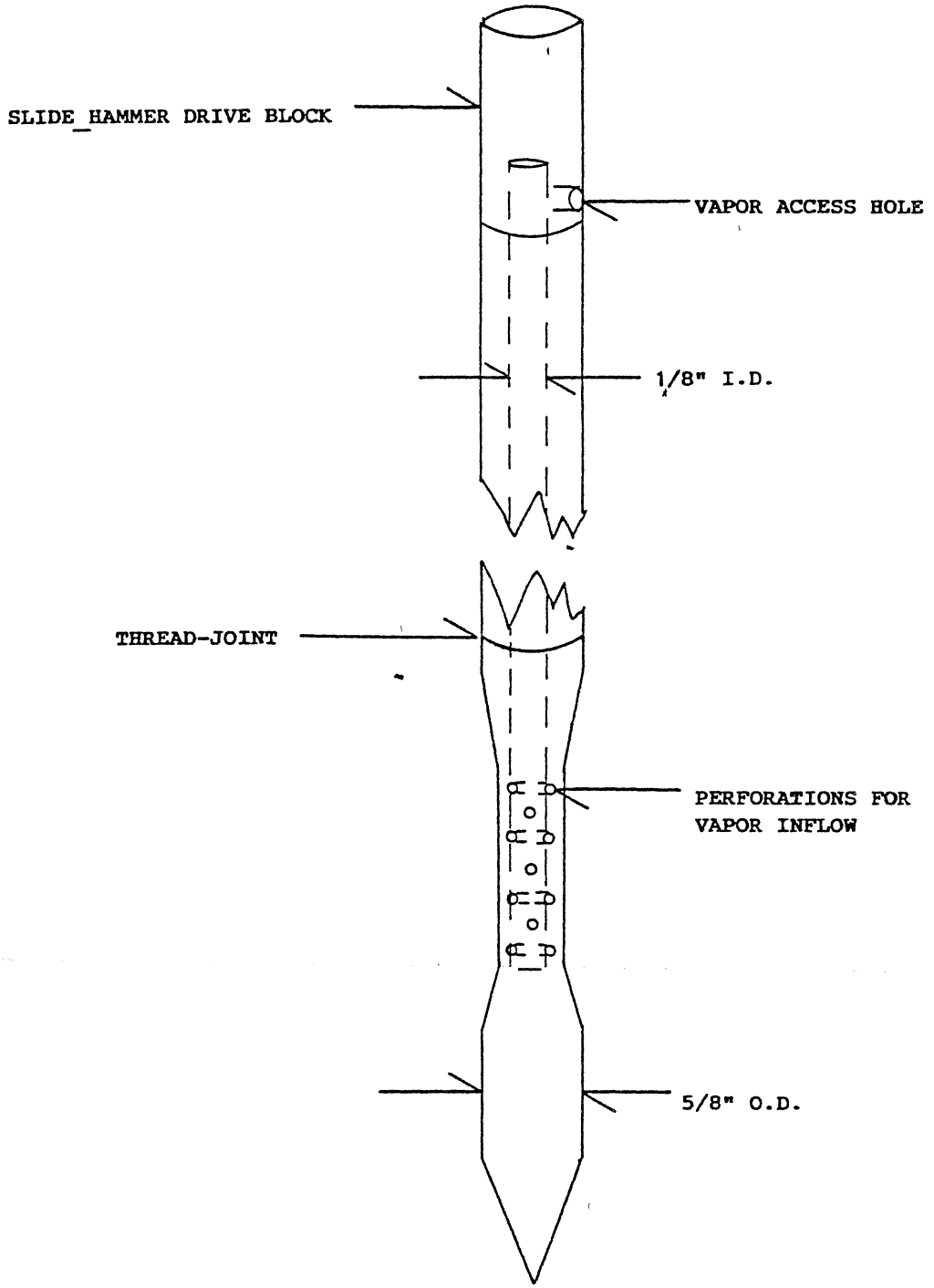


Figure 32. Soil vapor probe with fluted, perforated tip

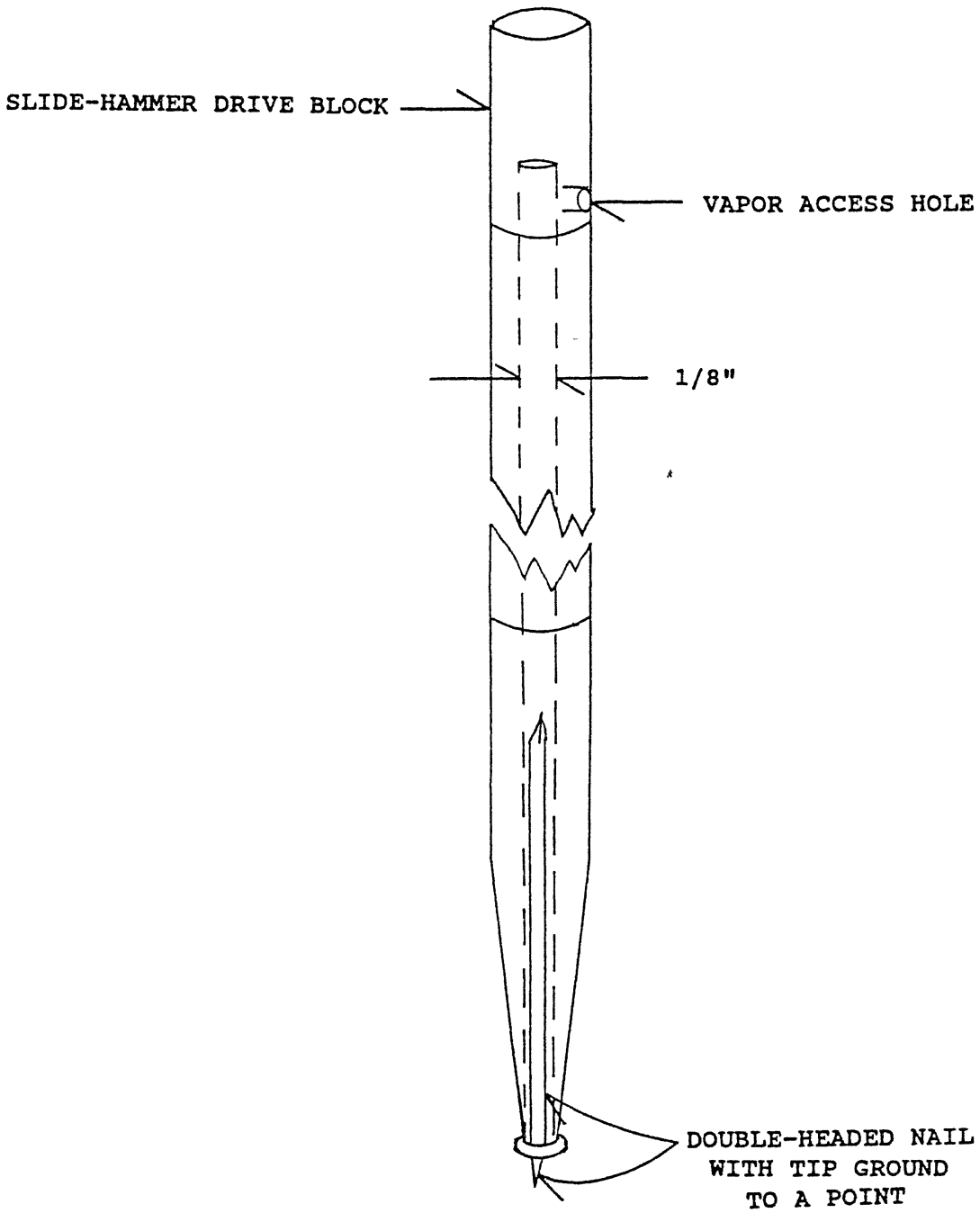


Figure 33. Soil vapor probe with retractible tip

apparently have too low permeability to allow movement of vapor through the soil and into the probe. This problem could be partially overcome by applying more vacuum pressure to the probe in order to increase the vapor flow rate. This would, however, increase the likelihood of ambient air leaking down the probe shaft and diluting the sample. Higher vacuum pressures also could change the liquid-gas equilibrium in the soil, thus producing a sample that was not representative of the in-situ vapor phase. The sampling vacuum pressure would then add a variable to the already complex soil-liquid-vapor system, further complicating interpretation of soil organic vapor concentration data. Greensfelder, et al (1989) concluded that neither vacuum pressure nor vacuum decay time is a reliable indicator of the accuracy of organic vapor concentrations from a driven probe (as postulated by Robbins and Temple, 1988). For these reasons, the alternative method of high vacuum pressure sample extraction was not pursued.

After removal of the soil probe at a location where a PID response of 0 units was obtained through the probe, a length of Teflon tubing was inserted into the open hole left by the probe, and a vapor sample withdrawn from the open hole. This sample produced a PID response of over 150 units. The driven probe had produced a false negative indication of organics in the soil vapor, apparently due to low soil air permeability. The open hole left by the probe

had accumulated organic vapors diffusing from the soil on the wall of the hole. This open soil probe hole could be regarded as a large soil pore or macropore; the organic vapors in this hole were establishing a concentration gradient toward the atmosphere. Upward diffusion within the open soil probe hole is not, however, affected by soil permeability. The rate of vapor diffusion through the soil surrounding the open probe hole wall may not be adequate to maintain a constant rate of diffusion through an open system to the atmosphere, and this would lead to reduction in the organic vapor concentration in the soil immediately surrounding the hole. However if the hole is capped at the top, equilibrium should eventually be established without depleting the source of hydrocarbon vapor at or near the bottom of the hole.

Sampling organic vapors from an open core hole is likely to result in organic vapor concentrations that differ from those collected from an in-place low volume soil probe. The open core hole is exposed to atmospheric conditions to a much larger extent than would be a soil probe. The equilibrium established in the open core hole will probably be more profoundly affected by atmospheric conditions, since there is no "buffer zone" of soil with its restricted flow regime, near-saturated humidity and low temperature gradient. The vapor collected from an open core hole is a mixture of atmospheric gases and soil vapor. The resultant organic vapor concentration in the capped

borehole may not be absolutely representative of that in the soil surrounding the bottom of the borehole, which is what would be obtained from a soil probe in soils with adequate permeability; however a correlative relationship is logically expected. A vapor sample which has a concentration that is correlative to that in the actual soil interstices is infinitely more desirable than no sample at all, or a false negative indication of the presence of organics in the soil.

Due to the inability of the available equipment to extract a vapor sample through the probe, and the inherent problems created by applying too large a vacuum suction, soil vapor samples were collected from holes left by a 1-inch soil core. This method also allowed the simultaneous collection of soil samples for soil descriptions and headspace organic vapor analysis or preservation for later laboratory organic or grain size analysis.

Soil Vapor Survey

Using the "open core hole" method to collect soil vapor samples, a soil vapor survey was conducted across the facility on a regular grid pattern, spaced 75 feet between sample points. The spacing was chosen based on preliminary knowledge of soil type in the area, which is silt loam and sandy silt loam, considered to be an intermediate soil type. In general, closer spacing is recommended for fine-grained soils than for coarse-grained soils (Devitt, et al,

1987). A north-south transect was first run approximately through the center of the known area of ground water impact to determine the extent of organics in soil vapor along this axis. Samples were collected along this line until PID response of 0 was obtained at either end. Several points were sampled at more than one depth to determine the optimal sampling depth of three feet. Soil descriptions were recorded periodically and whenever significant changes in texture were observed. Soil vapor samples were then collected along an east-west transect through the area of highest concentration on the north-south transect to define the extent of impact along this axis. The remainder of the area was then filled in on the 75 - foot grid spacing until at least one zero PID response was encountered on all lines.

Soil Vapor Port Construction and Site Selection

For long-term monitoring of soil organic vapor concentrations for comparison to changing soil moisture and atmospheric conditions, soil vapor "ports" were installed at four locations with differing juxtaposition to the liquid hydrocarbon plume. Figure 4 (page 30) illustrates a typical soil vapor port installation. The locations for these ports (Figure 34) were chosen to provide comparison of soil organic vapor concentration changes in relation to

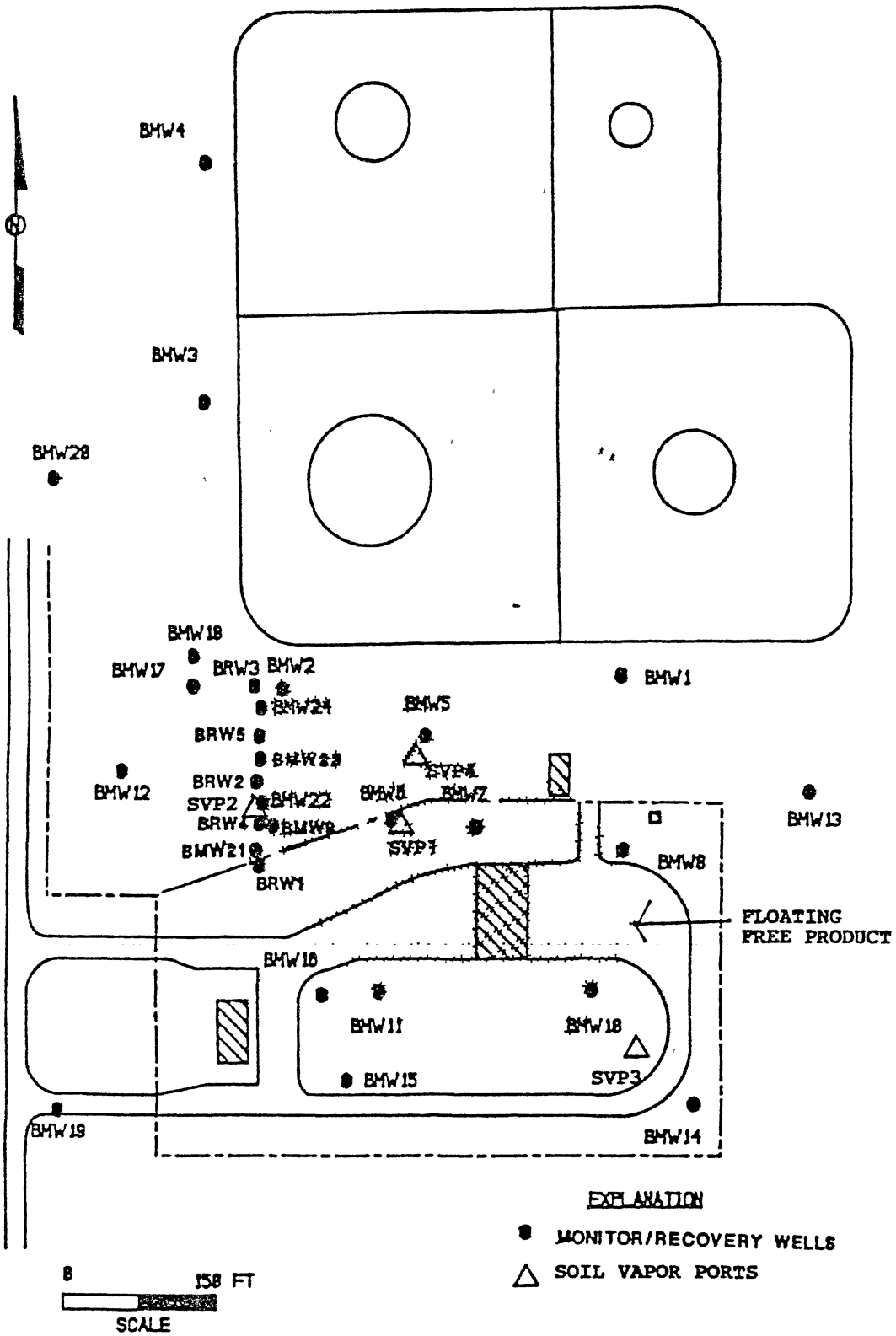


Figure 34. Soil vapor port location map

distance from the liquid hydrocarbon. The ports were installed in an open hole left by a 1 inch diameter soil core. A small amount of washed sand was poured into the bottom of the hole to act as a filter pack and quarter-inch polyethylene tubing was inserted into the hole, with a 3/16" steel rod inside it to keep the tubing straight and to keep soil from plugging the tubing while it was inserted. It was not considered necessary to use Teflon tubing in the permanent ports since they are to be left in the ground. Polyethylene will adsorb hydrocarbons, but the vapor/solid adsorption will reach equilibrium and thus should not affect concentrations over the long term. Sand was poured to fill approximately 6 inches of the annulus, and sodium bentonite slurry was then poured to fill the remainder of the annulus. The ports were allowed to stand undisturbed for at least a week before a vapor sample was extracted. The ports were checked with a vacuum pump equipped with a gauge to determine whether they were plugged with soil. If a port was found to be plugged, it was removed, the resulting hole was plugged with bentonite slurry, and another port was installed to replace it. (This was necessary only one time). The soil vapor ports are similar to a driven probe in that they are sealed around the tubing annulus, therefore they theoretically allow collection of a representative sample of the vapor from surrounding soil interstices.

As a standard quality control measure, the ports were

purged of at least one soil core hole volume before samples were collected. The diaphragm-type sample pump used is rated at 500 cubic centimeters per minute, and the vapor port volume (including the sand filter pack) is approximately 6.5 cubic inches, or 107 cubic centimeters; thus only about 13 seconds was required for purging. However 30 seconds was allowed to insure proper purging of non-soil vapors.

Samples were extracted from the soil vapor ports on approximately a weekly basis from January through April, 1991, and several times in May and June. (One exception is Soil Vapor Port #3; the vapor concentration in this port fell to immeasurably low levels, so sampling was discontinued for this port). All weather conditions were recorded during each sampling event.

During most sampling events a soil sample was collected, at the same depth as the soil vapor port inlet (3 feet below surface), within 4 feet of the port location, with a one-inch soil core for measurement of moisture content. The standard soil coring tool (figure 35) proved to be too fragile for repeated sampling, so a low cost disposable tool was designed, implementing galvanized iron electrical conduit modified for extraction of a soil sample (figure 36). A vapor sample was also collected from the open hole left by the soil core, in the same way that vapor samples were collected during the soil vapor survey, for

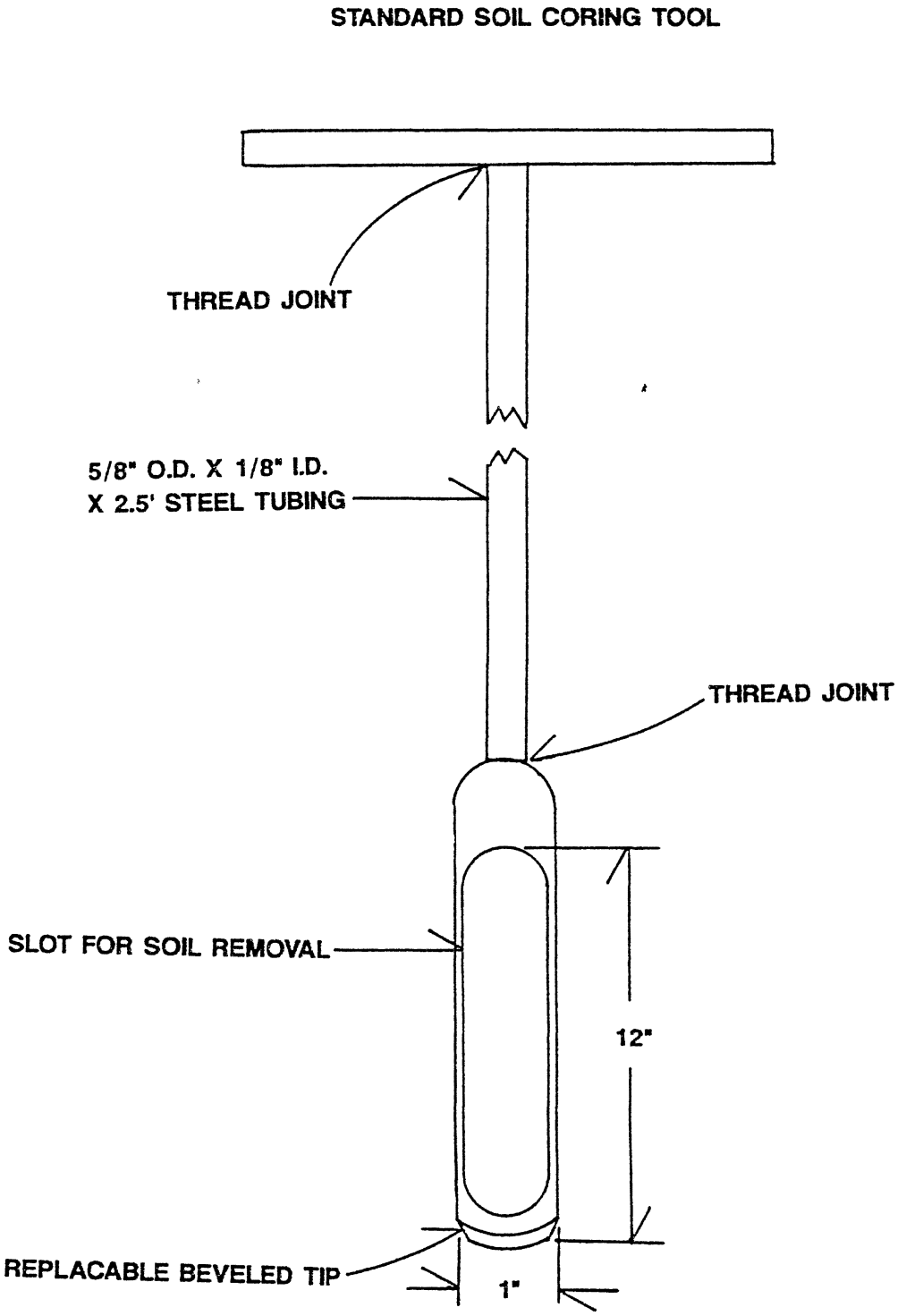


Figure 35. Standard soil coring tool

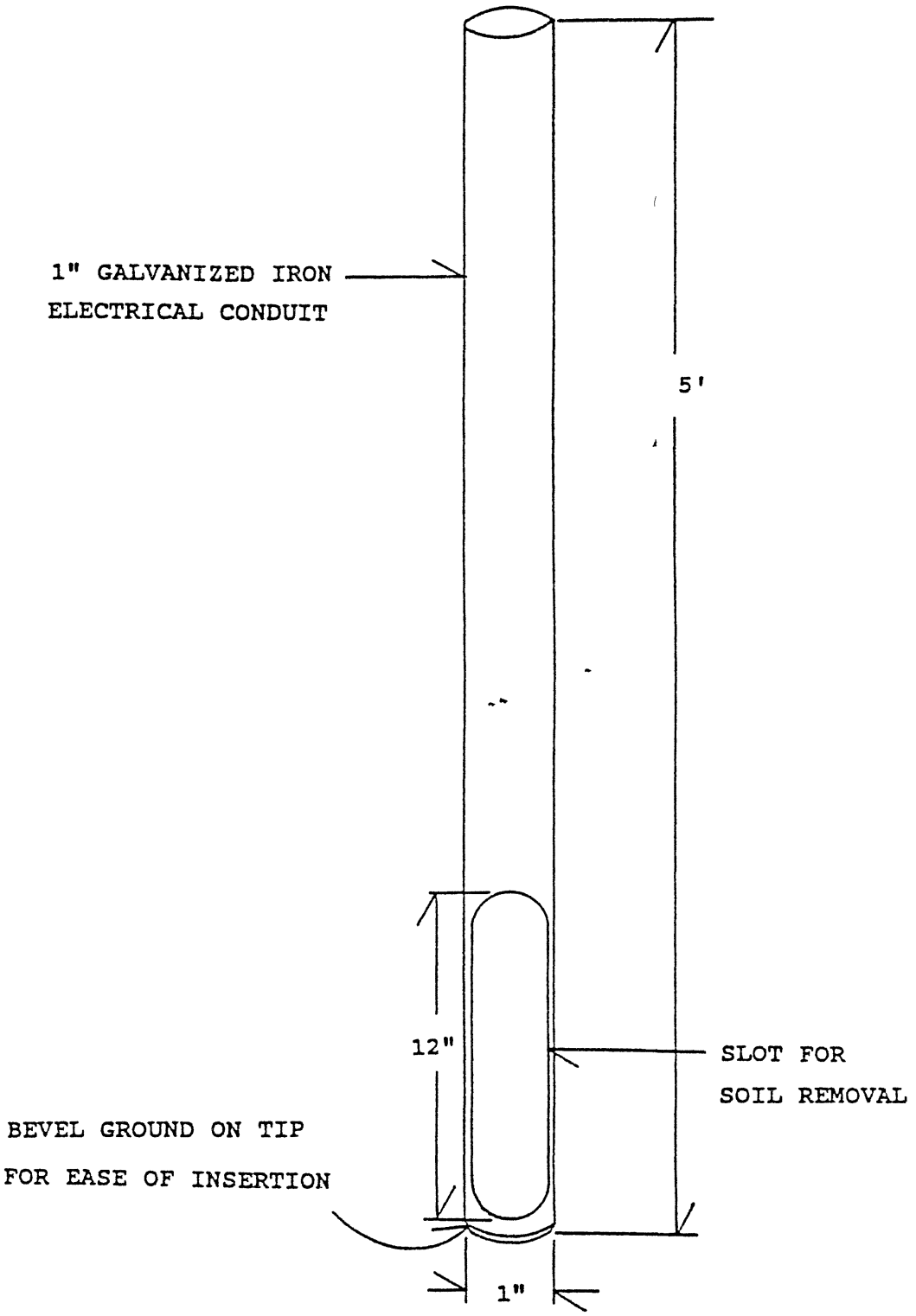


Figure 36. Soil coring tool made from 1" electrical conduit

comparison of the core-hole vapor sample concentrations to the soil vapor port samples and the simultaneously recorded environmental variables. After sampling, the open core holes were plugged with bentonite powder or pellets; water was poured into the hole after the bentonite every few inches to insure hydration of the bentonite. By plugging the holes with hydrated bentonite, problems of excess soil aeration or induced infiltration of precipitation through the core holes were avoided, and the "in-situ" qualities of the soil were maintained as well as possible.

Soil Vapor Sampling and Analysis Methods

Soil Vapor samples were collected from the core holes by pumping vapor with a hand-held battery-operated air sampling pump into the PID or into a Tedlar bag for later measurement with the PID and/or the portable GC. A thin (1/16" inside diameter) Teflon tube was inserted into the open core hole inside of a 1/4" stainless steel tube with a flare at the bottom (Figure 37). The outer tube was utilized to keep the Teflon tubing straight, and to prevent scraping the core hole walls, which could plug and/or contaminate the Teflon tubing. The flare on the outer tubing was found to help allow any soil that was accidentally scraped off the side of the borehole to fall into the hole instead of sticking inside the tubing. The sampling pump was connected to the Teflon tubing, then to the OVM or a Tedlar sample bag. The tubing and/or the pump

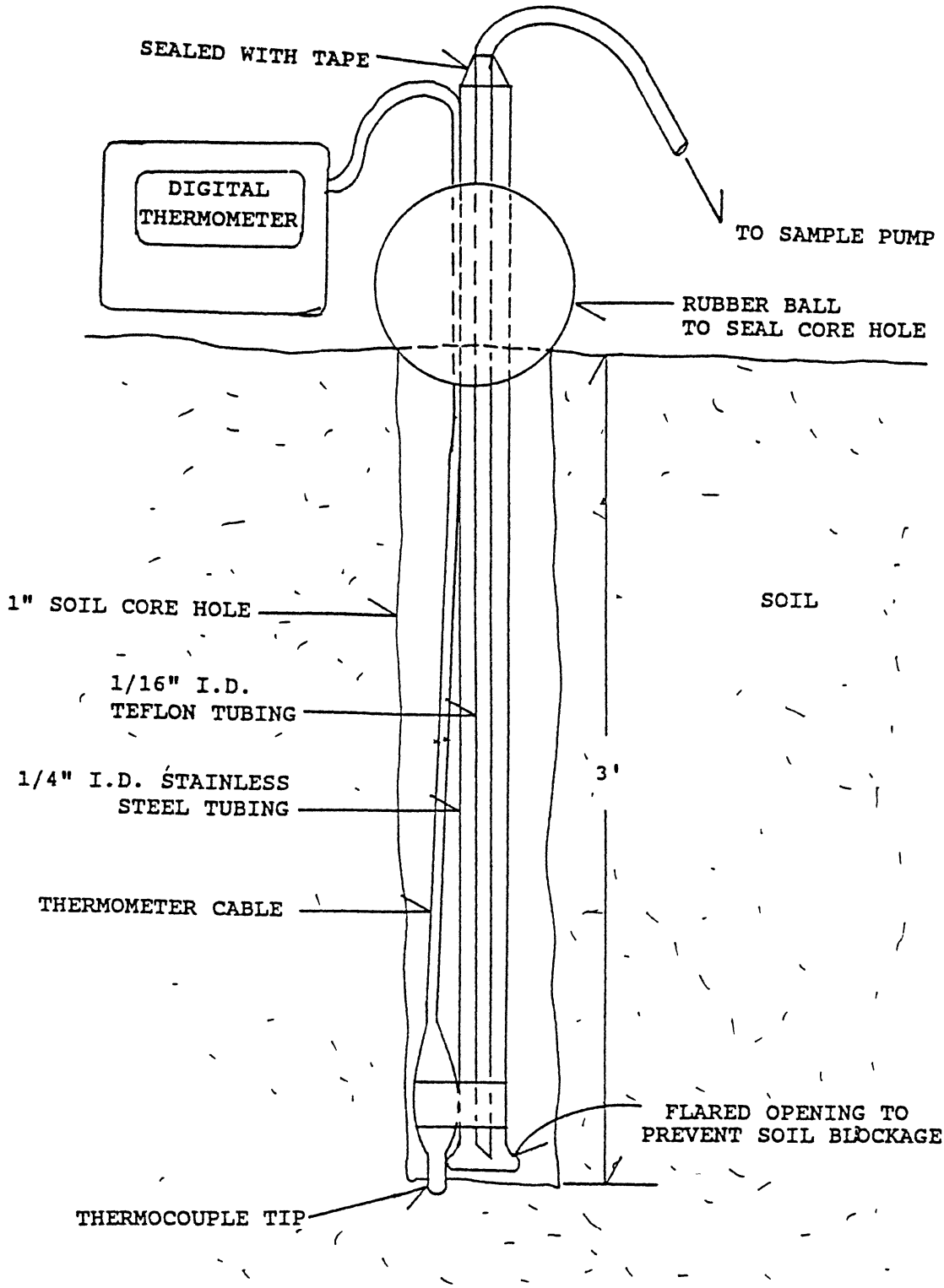


Figure 37. Core hole soil vapor sampling tool

adsorbed some hydrocarbon vapors as they circulated; to eliminate problems of cross-contamination, the pump was allowed to run continuously between samples, drawing ambient air through the tubing and the pump to purge remnant hydrocarbon vapors. Before successive vapor samples were collected, the output of the sampling pump was checked with the PID to make sure no contamination remained. The Tedlar bags were purged by repeatedly filling them with ambient air and venting them; the PID was also used to check the Tedlar bags for remnant hydrocarbon vapors to prevent cross-contamination of samples.

The soil vapor ports were sampled much in the same manner, except that the tip of the PID was sometimes inserted directly into the tubing of the vapor port, and a vapor sample extracted using the internal pump of the PID, instead of using the air sampling pump.

Soil vapor samples were measured for organic content with a Thermo-Environmental Instruments Model OVM 580A Photoionization Detector. This instrument is equipped with a 10.0 electron-volt ultraviolet lamp for excitation of organic vapor molecules, and produces a concentration value in nominal parts per million on the digital readout. The PID is calibrated with isobutylene, thus it will measure isobutylene concentration in parts per million: the response to other organic vapors will vary, and cannot be quantitated with this instrument unless the instrument is calibrated with the compound being measured. Because the

vapor components being measured in this study are not specifically identified, the concentrations produced with the OVM are referred to as units of Total Ionizable Vapors, or TIV.

During periods of extremely high temperature and relative humidity (greater than 90^{o} F and 90% relative humidity) or very low temperatures (less than 40 degrees F) the PID became inoperable in the field and samples had to be preserved for later analysis indoors, under normal temperature and humidity conditions. The problems with PID operations at low temperatures are apparently also due to high relative humidity conditions. While no documentation is available to explain the aberrant behavior of the PID, the following is this researcher's interpretation of the observed phenomena: the warm, humid soil vapor is super-saturated with water vapor with respect to the ambient air. Upon entering the ionization chamber of the PID, the vapor condenses on the lens of the UV lamp, causing the PID to lose its zero reference, and concentration readings become meaningless. At moderate ambient temperature and humidity the relative humidity of the soil vapor is apparently low enough in the PID ionization chamber to allow normal instrument operation. Other problems were encountered with the PID, as discussed in the "Sources of Errors" section of Chapter V.

Later in the study a portable GC, a Sentex Brand Scentograph Model portable gas chromatograph became

available for use. This instrument is equipped with an Argon gas ionization detector and a packed column for separation of vapor constituents by molecular weight. The GC is calibrated using a standard mixture of gases of known concentration (BTEX, or benzene, toluene, ethylbenzene and xylene). The output of the GC is a chromatogram, which is a graph of constituent concentration vs time as the constituents move through the elution column; a portable computer integrates the area below the curve for each constituent for comparison to the calibration and calculates a resultant concentration. Sample components which are not contained in the calibration standard are referred to as unknowns; a concentration may be calculated by the computer using the area of the curve, but concentration of unknowns are not reliable numbers. Soil vapor samples were pumped directly from a Tedlar bag into the GC using the built-in sample pump, or samples were extracted from the Tedlar bags with a specially designed syringe, and injected into the injection port of the GC. Concentration readings from the GC were then compared to those obtained from the PID. The instruments are not expected to produce equivalent concentration values, because of their different detector types and calibration standards, and because the samples contain unknown constituents.

Measurement of Soil Vapor Oxygen Content

As the study progressed it became apparent that the photoionization detector was becoming "attenuated" by high concentration vapor samples. (This is discussed further in the "Sources of Errors" section of Chapter V). It was suspected that low oxygen content may have been causing this effect; therefore a Scientific Instruments Model 260A combination oxygen meter-explosimeter was used to measure soil vapor oxygen content in three of the vapor samples. The oxygen meter, which has an internal pump, was connected to vapor samples stored in Tedlar bags from vapor ports 1,2 and 4.

Soil Sampling

Soil samples were collected with a 1-inch diameter soil core and retained for analysis of moisture content and grain size distribution. Samples were collected at 1-foot intervals for observation of grain size changes with depth. Since the sampling depth for organic vapors was 3 feet, the first two 1-foot intervals were simply put into plastic bags for air drying and later grain size analysis. The sample from 2 to 3 feet was immediately placed in a sealed plastic bag to prevent moisture loss, while a vapor sample was collected from the borehole. When the vapor sampling was completed, a 250 ml. glass jar with a Teflon-lined lid was loosely filled with soil and sealed for measurement of

moisture content. The remaining soil sample was put in a sealed plastic bag for measurement of organic vapors in the headspace, or in an unsealed plastic bag for air drying and later grain size analysis.

Soil moisture content was measured using ASTM recommended procedures: the wet soil was weighed to the nearest 0.1 gram and placed in a vented oven for drying at 110 degrees Centigrade for 24 hours. It was then weighed again, and the dry weight subtracted from the wet weight to obtain the weight of water that was in the soil. This number was then divided by the weight of the wet soil to obtain the moisture percentage of the soil by weight.

Soil grain size distribution was also determined using ASTM recommended procedures. The air-dried soil samples were pulverized with a rubber-covered pestle to break up agglomerations. The pulverized soil was then divided by quartering to obtain the desired mass of soil for screening. This quantity was weighed to the nearest 0.1 gram and recorded as the mass of the test sample, uncorrected for hygroscopic moisture. Standard soil screens numbered 4, 10, 20, and 100 were used in this analysis. The soil sample was then placed in the top screen and shaken in an electric powered screen shaker. The weight of soil remaining in each screen was measured to the nearest 0.1 gram, and this weight was divided by the weight of the total sample to obtain the percentage in each grain size category. The weight of all the screened

material was summed and divided by the mass of the test sample to obtain the percentage of material recovered after the test procedure. Appendix C contains soil grain size analyses data.

Soils were analyzed for volatile organic content by GC analysis, by laboratory GC. Soil samples were collected in 40-ml. volatile organic analysis (VOA) jars equipped with Teflon septa. The soil samples were prepared by sonication (ultrasonic mixing), using water solvent for laboratory analysis. Nitrogen carrier gas was then bubbled through the solution and pumped into the laboratory GC for analysis. Resultant concentrations were then compared to PID and portable GC responses in corresponding vapor samples. Again, concentrations are not expected to be equivalent, since all these machines use different detectors and different sample preparation techniques were used. Both GC's were calibrated to measure benzene, toluene, ethyl-benzene and xylenes (BTEX).

Ground Water Sampling

Ground water from several of the monitoring wells in the area was sampled for laboratory analysis for benzene, toluene, ethylbenzene and xylenes (BTEX). These compounds are constituents of interest because of their ubiquitous presence in gasoline, their relative solubility and volatility (with the exception of xylene) and their presence on the "Skinner's" list of hazardous chemicals,

which is often referred to for analytical requirements at locations where hazardous materials have impacted the environment. The portable gas chromatograph used in this study also was calibrated to measure BTEX concentration; thus portable GC results may be equivalently compared to laboratory analyses. Finally, BTEX is the "standard" indicator used in analysis for gasoline contamination.

The well logs for the sampled wells were inspected to determine the depth of the well; the water level in each well was measured prior to sampling, and a saturated thickness calculated for each well. This thickness was multiplied by pi times the square of the casing radius to result in the saturated casing volume for the well. Three times this volume was bailed from each well with a 24" long by 1.25" I.D. bailer before a water sample was retained in a 40 ml. vial with a Teflon septum in the lid. Samples were immediately placed in a cooler with ice for storage before shipment. The bailer was thoroughly cleaned with laboratory grade detergent, thoroughly rinsed with tap water, then triple-rinsed with de-ionized water between sampling different wells. The samples were then carefully packed in an iced insulated shuttle with a chain of custody form which specified the type of analysis required, and shipped by overnight air express to the laboratory.

Headspace Sampling of Ground Water Monitoring Wells

The headspace vapor in selected ground water monitoring wells at the site were sampled and analyzed with the PID and the portable GC. Results were compared to the laboratory analyses of ground water samples, to evaluate the potential for using headspace vapor in wells as an indicator of ground water contamination by volatile organics.

Headspace samples were collected from the wells according to the following procedures: the depth to water (or floating hydrocarbons) was first measured in each well. A length 1/16" I.D. Teflon tubing was then lowered into the well to 0.5 feet above the fluid level. The air sampling pump was connected to the tubing, and a vapor sample was pumped out into a 1-liter Tedlar bag. The PID was then connected to the bag and a concentration reading recorded. A calibrated syringe was used to extract a sample from the bag and to inject it into the injection port of the GC, in the same manner as other vapor samples.

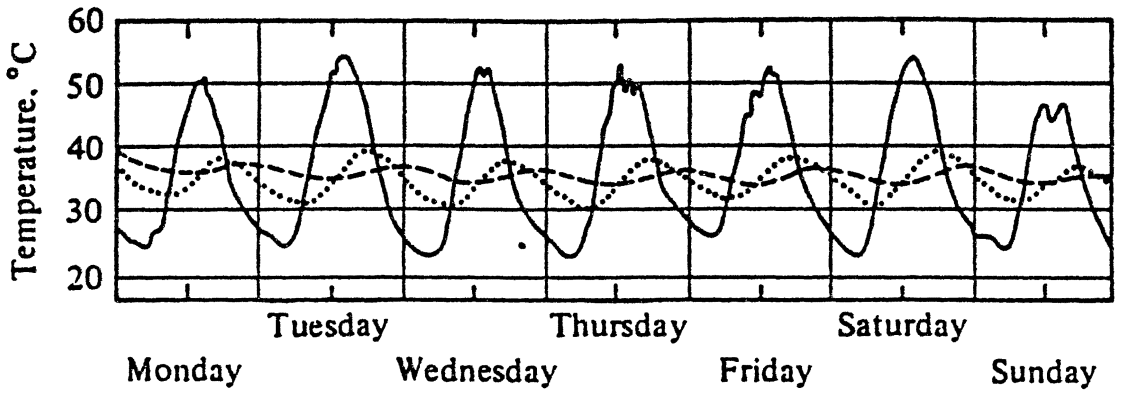
Soil Temperature Measurements

It became apparent after several sampling events that soil temperature may be affecting soil vapor organic concentrations. Therefore a remote temperature probe was obtained and affixed to the bottom of the tube used for

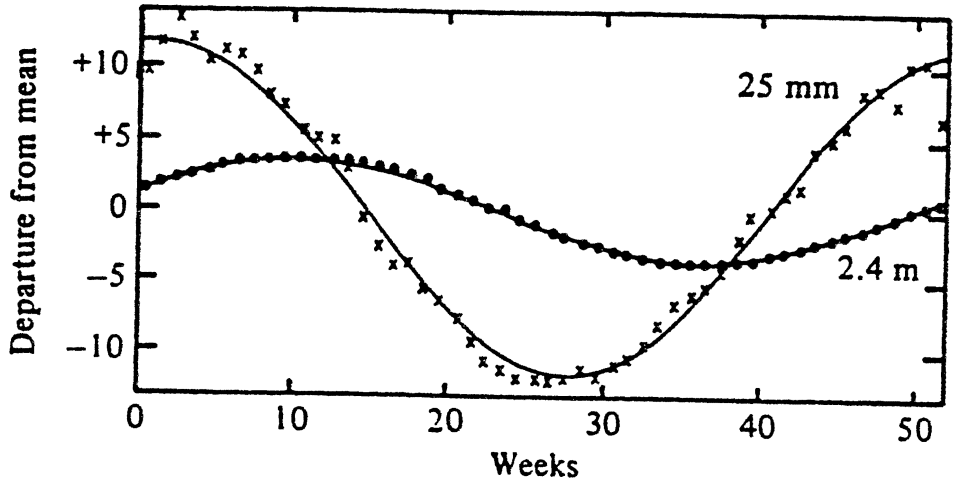
soil vapor sample collection (Figure 37, page 100). This allowed measurement of soil temperature simultaneously with organic vapor sampling. The temperature probe, which extended in front of the opening in the vapor extraction tube, was pushed into the soil and left in place until the temperature reading on the digital display ceased to change.

Soil temperature changes as a function of daytime absorption of short-wave radiation from the sun and nighttime emission of long-wave radiation from the earth. This results in a daily, or diurnal cycle, as well as a seasonal or annual cycle of temperature change which follow a sinusoidal pattern of change (Figure 38). These cycles are most pronounced at the surface, and decrease in intensity with depth, until at approximately 0.3 meters the diurnal cycle is decreased to 5 percent of the amplitude at surface, and at approximately 6.5 meters the annual cycle is decreased to about 5 percent of the surface amplitude. The amplitude of the soil temperature cycle decreases exponentially with depth (Marshall and Holmes, 1988).

Figure 39 shows the annual monthly average soil temperature cycle at Ada, OK, measured at 4" below surface during 1989, as well as the average monthly air temperature values. (This was the closest soil temperature data obtainable). The monthly average soil temperature cycle amplitude during 1989 at Ada was 44.15" at 4" from surface. The temperature was recorded at the soil vapor sampling



DIURNAL TEMPERATURE WAVE IN SOIL AT THREE DEPTHS DURING A WEEK IN MIDSUMMER AT GRIFFITH, AUSTRALIA
_____ 10 mm depth; ..... 25 mm depth
- - - - 300 mm depth



ANNUAL TEMPERATURE WAVE IN SOIL AT TWO DEPTHS FOR 52 WEEKS COMMENCING JANUARY 1. DATA POINTS ARE AVERAGES FORMED FROM 8 YEARS OF RECORDS AT GRIFFITH, AUSTRALIA (WEST, 1952)

Figure 38. Diurnal and annual soil temperature wave graphs

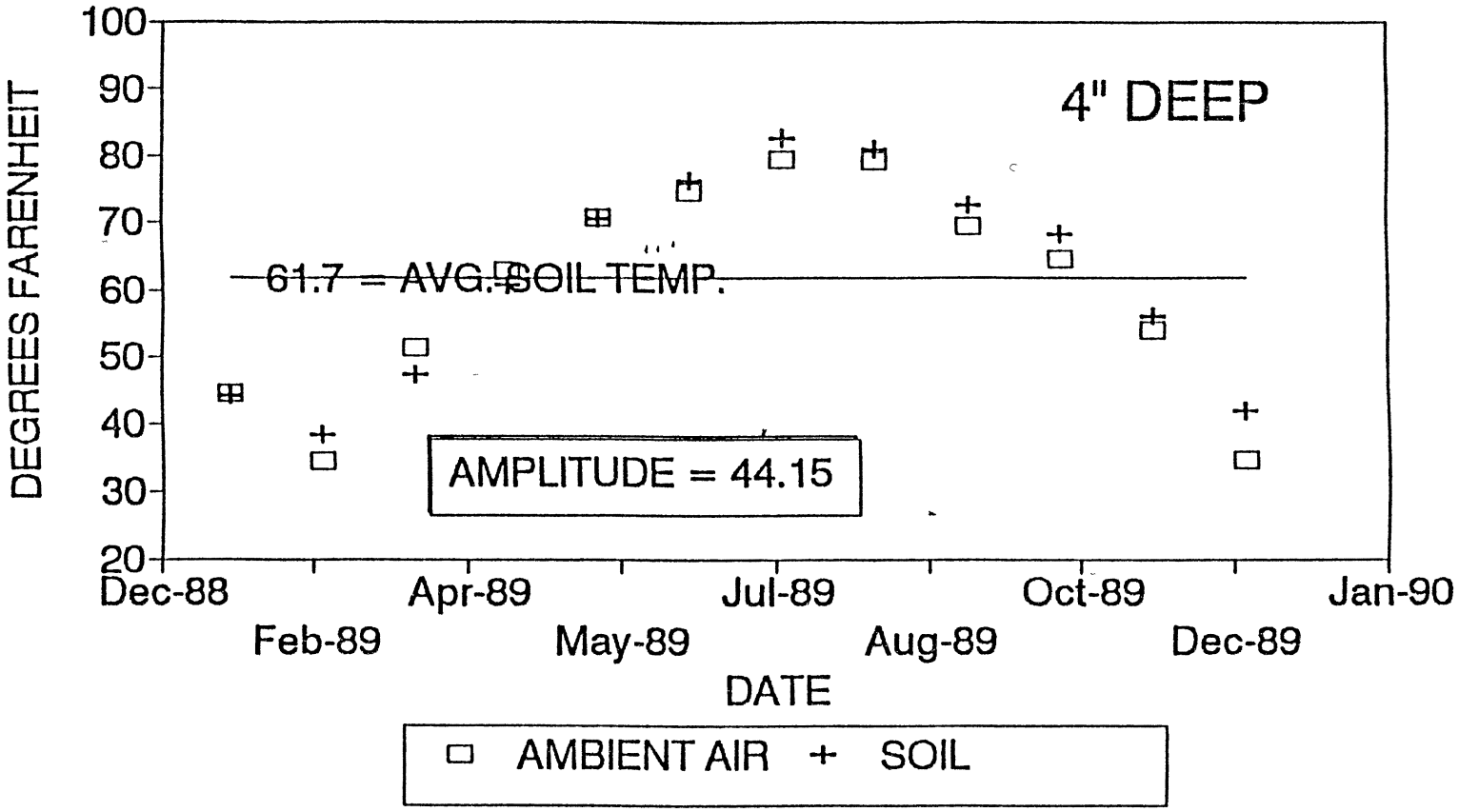


Figure 39. Annual soil temperature wave at Ada, OK, 1989

depth of approximately 3 feet, or 0.9 meters from surface in this study: diurnal changes would be expected to be insignificant at this depth. However the annual cycle will have an amplitude of approximately 30 inches.

Soil temperature was not recorded during the first several sampling events in the subject study. Because soil temperature apparently has a pronounced effect on volatile organic vapor concentration, the soil temperature at the study site was estimated where missing from the data, for purposes of statistical calculations. To make this estimation, it was assumed that the soil temperature at Ada closely resembled that at the study site; Ada is approximately 32 miles east northeast of the study site, and the soil type at the measurement station is similar, a sandy loam.

Soil thermal conductivity is a function of its mineral composition, bulk density or compaction (hence porosity), and the proportion of water-filled to air-filled porosity. Greater bulk density and greater water content both increase the thermal conductivity of soils (Marshall and Holmes, 1988). Thus soil temperature would be expected to increase at a more rapid rate after a rainfall, when the water content is higher. The recorded soil temperatures do not fall precisely on a sine curve, due to this effect as well as variations in the amount of sunlight striking the ground. However the estimated soil temperatures are believed to be reasonably accurate; an error of a few

degrees is not expected to create problems with statistical analyses; the general trend of temperature change with time is believed to be more important for this study than the absolute value of the soil temperature.

Figure 40 shows the estimated and measured soil temperature values plotted with the measured ambient temperature values during the period of this study, from January to June, 1991. The soil temperatures observed at this site were higher than would be expected, as compared to the Ada soil temperatures. The higher temperatures are probably due to increased biotic activity in the soil, as soil microorganisms oxidize the organics in the soil. This increased temperature would also serve to increase volatilization of organics into the atmosphere, reducing the amount of organics present.

Depth to Fluid Measurements

During each sampling event the depth to fluid was measured for each sampling point by measuring the depth to water or floating product in nearby monitoring wells with an interface probe or an electric water level indicator. The sample stations were all located within several feet of a monitoring well, with the exception of sample site 3, which was located exactly in between BMW10 and BMW14. The depth to fluid in these wells was simply averaged to obtain the depth to fluid in SVP3. The casing stickup plus three

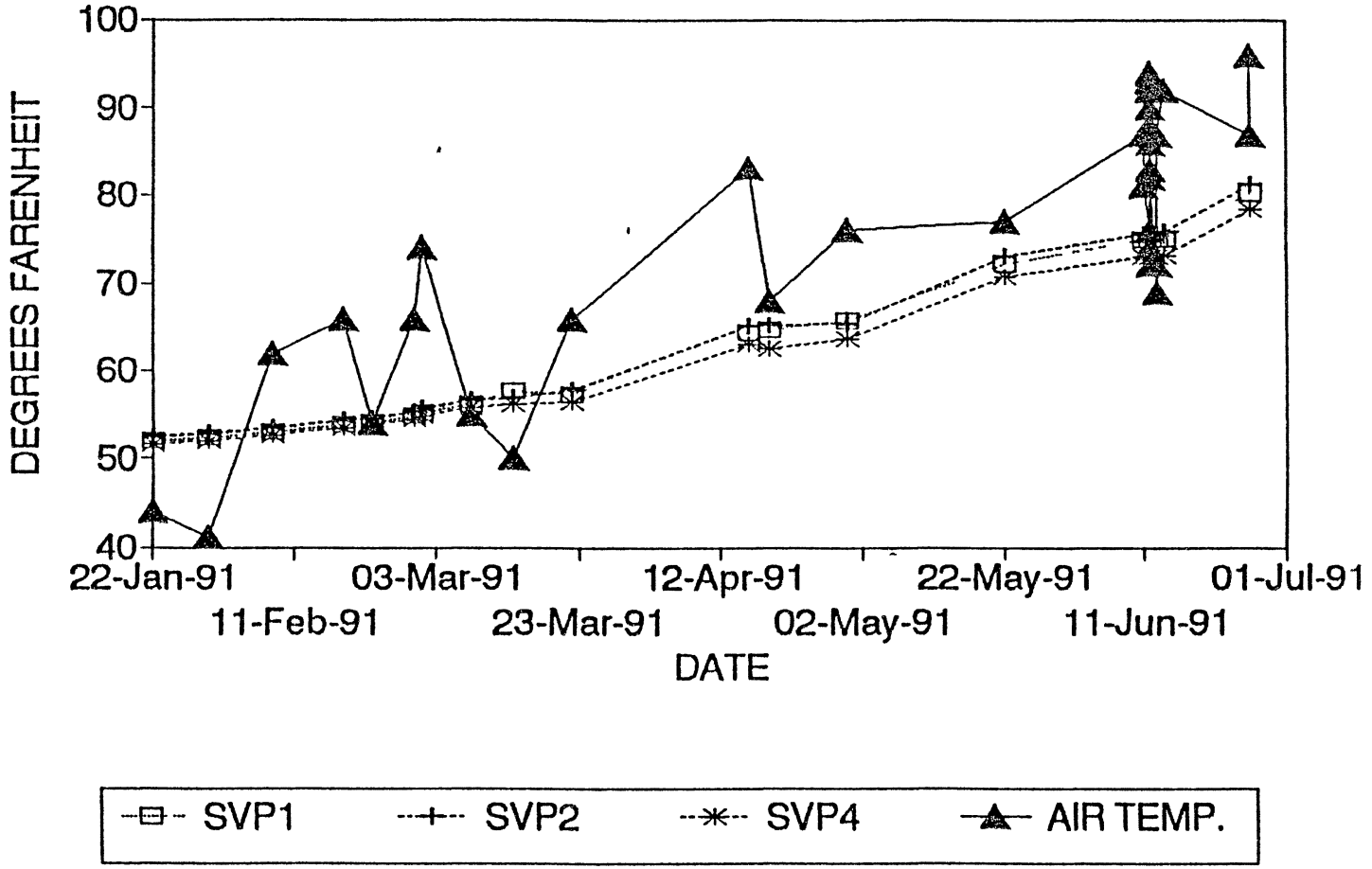


Figure 40. Graph showing measured ambient temperature and measured and estimated soil temperature at 3 feet below surface at the study site

feet (the depth of investigation) was subtracted to obtain the depth to fluid at the sampling point.

Measurement of Atmospheric Conditions

Atmospheric conditions were measured on site during each sampling event. Temperature, barometric pressure, relative humidity and wind speed were measured on site using standard analog instrumentation; a thermometer, a barometer, a hygrometer and an anemometer.

A rainfall gauge was kept on site, but it was not possible to be on site constantly to record weather conditions, thus on site rainfall data was not used. In lieu of daily on-site recordings, the nearest available daily weather records were sought, and found at Pauls Valley Oklahoma, from the Oklahoma Climatological Survey. Daily high and low temperatures were also recorded at Paul's Valley). Paul's Valley lies approximately 7.5 miles north from the study site. Figure 41 illustrates daily rainfall, and Figure 42 illustrates the daily temperature range at Paul's Valley.

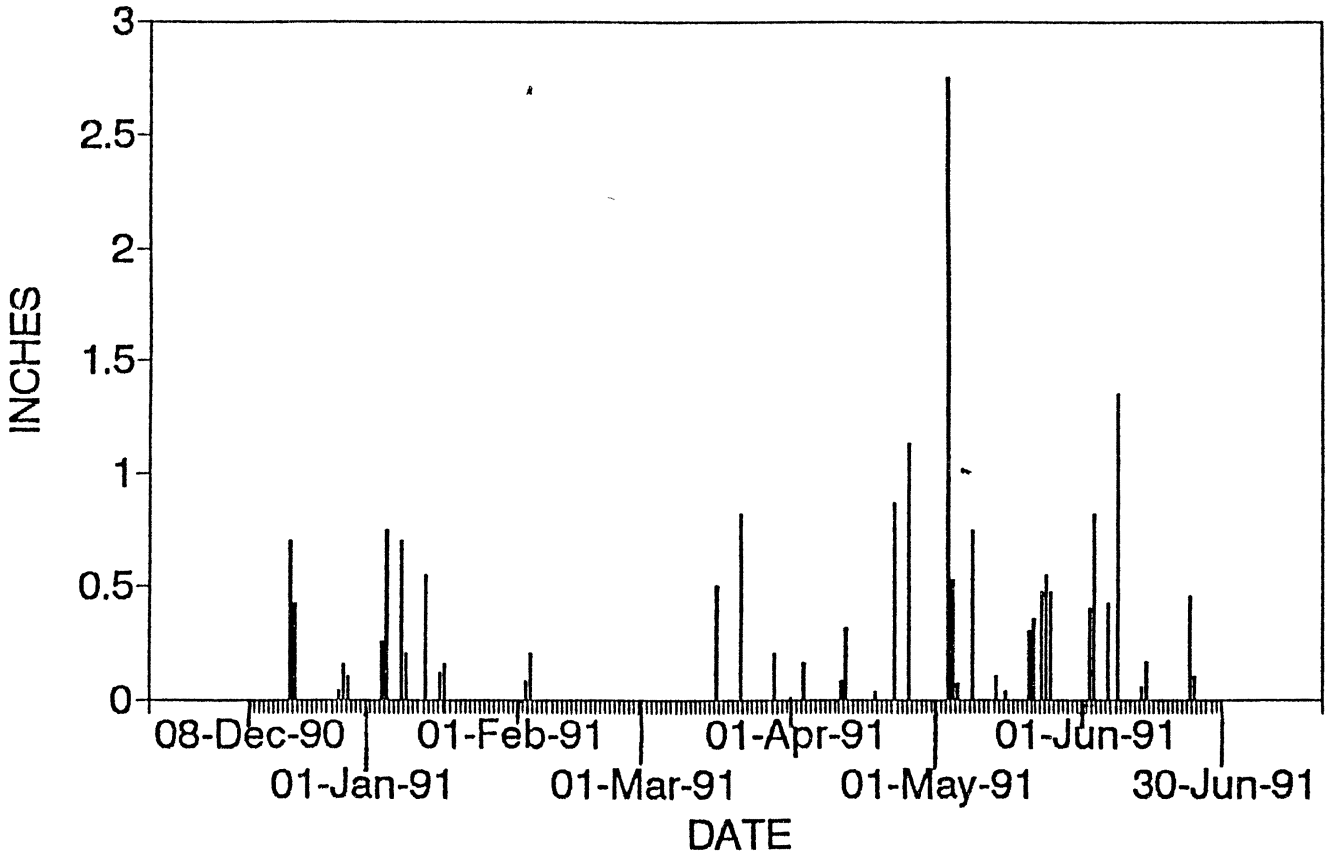


Figure 41. Daily precipitation at Pauls Valley, OK during period of study

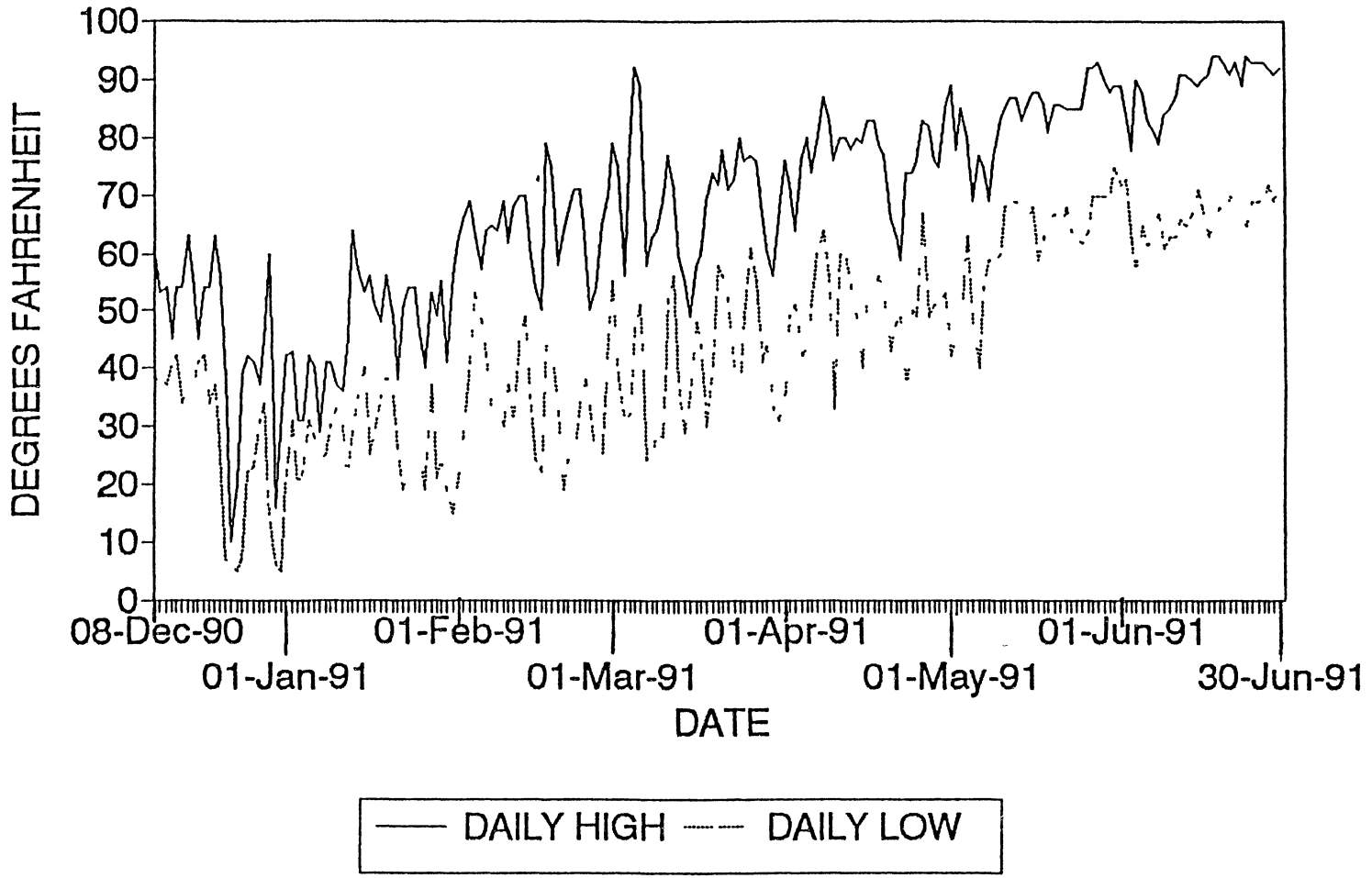


Figure 42. Daily high and low ambient temperature at Pauls Valley, OK during period of study

CHAPTER V

EXPERIMENTAL RESULTS AND INTERPRETATIONS

Soil Vapor Survey

A survey of volatile organic vapor concentration in the soil was conducted across the study site, during a 3-day period from December 10 through 12, 1990. The area was surveyed on a 75-foot centered grid, as illustrated by Figure 43. (Some grid points were inaccessible because of pavement or buildings; samples were collected as close as possible to these points). The depth of investigation for the survey was 3 feet below surface; this depth was determined both by knowledge of the depth to ground water, and by taking vapor measurements at several depths in several sample points to find the optimum.

Vapor concentration was measured with the Thermo-Environmental Instruments OVM Model 580-A photoionization detector, and recorded as units total ionizable vapor (TIV). Soil vapor samples were obtained by coring to 3 feet with a 1-inch diameter coring tool, then inserting 1/16" I.D. Teflon tubing into the hole inside a length of 1/4" O.D. stainless steel tubing (Figure 37, page 100), and withdrawing a vapor sample directly into the PID. The maximum PID response was recorded for each location. The

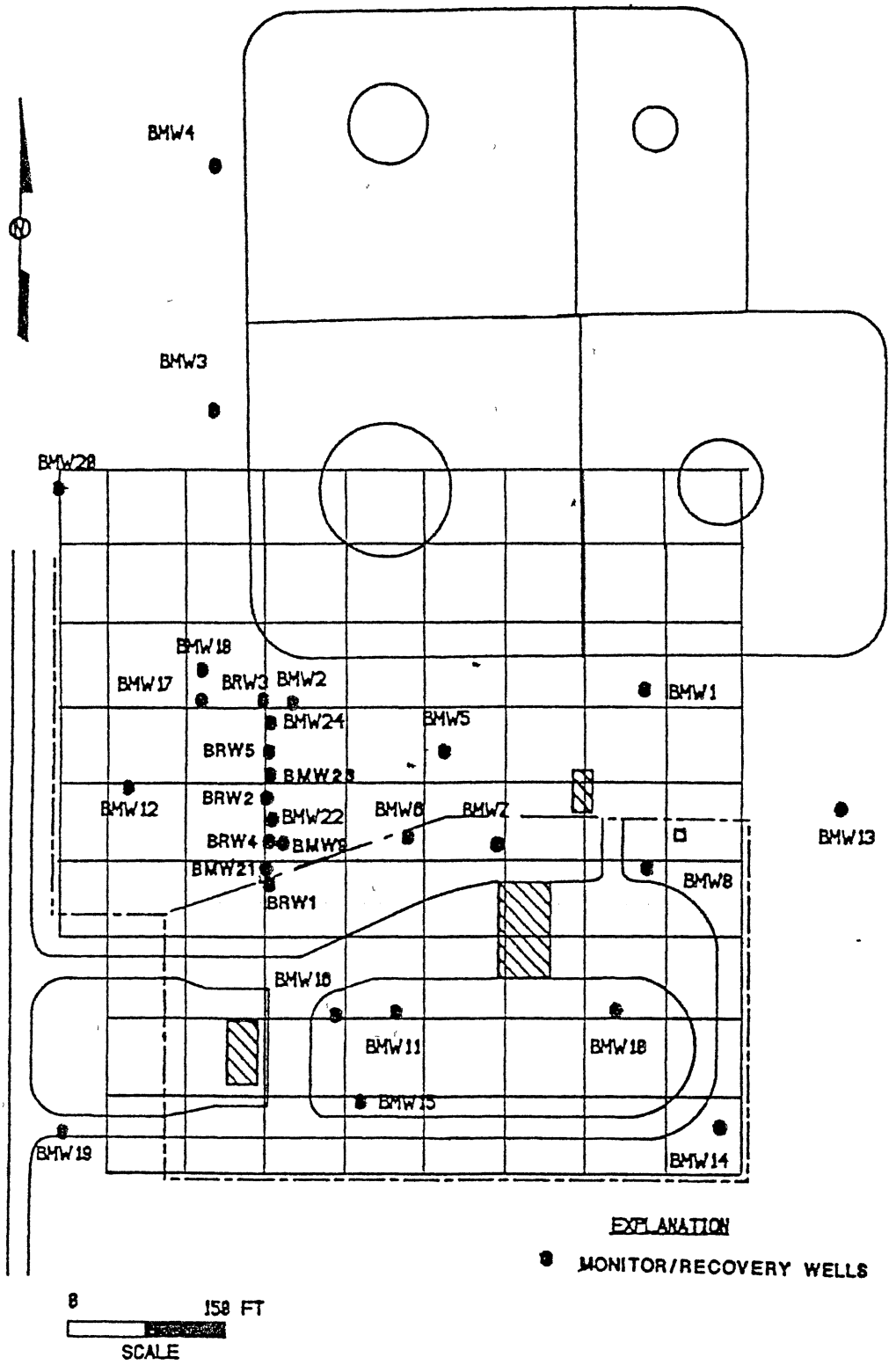


Figure 43. Soil vapor sampling grid

PID apparently has difficulty measuring very high concentrations. When highly concentrated organic vapors are encountered, the instrument response first increases, then rapidly decreases and approaches a stable but low response. Then when the vapor source is removed or diluted with ambient air, the response immediately increases to a maximum, then declines to "background". The maximum value was recorded, since it was rationalized that the PID could not respond with a high value unless the concentration were high. The high concentrations were verified by smelling the vapor; where the PID displayed the characteristic suppressed response followed by a sudden instantaneous increase, the vapor had a very strong petroleum odor. Concentrations were recorded on a field data formed devised especially for this project. Figure 44 is an example of this form.

Soil Organic Vapor Concentration Map

Figure 45 is a map of sample stations and corresponding maximum Total Ionizable Vapor concentrations across the entire area of study, and Figure 46 shows these values contoured on an interval of 50 units. The map indicates the area of highest concentration around the truck loading rack area and extending to the west-northwest. Figure 47 shows the concentration isopleths overlain on a map of the extent of liquid hydrocarbons

SOIL VAPOR MEASUREMENT
FIELD DATA FORM Page_____of_____

SITE NAME _____ TYPE OF STUDY _____

SAMPLE POINT_____ DATE, TIME _____
AMBIENT TEMP _____ HUMIDITY _____ BAR. PRESS._____
WIND MPH _____ INSOLATION _____ SOIL TEMP _____
SAMPLE TYPE: ANALYSIS TYPE AND RESULTS
GROUND PROBE _____
CORE HOLE _____
SOIL HEADSPACE _____
PERMANENT PORT _____
OTHER (DESCRIBE) _____
NOTES: (SOIL DESCRIPTION, UNUSUAL CONDITIONS, ETC.)

SAMPLE POINT_____ DATE, TIME _____
AMBIENT TEMP _____ HUMIDITY _____ BAR. PRESS._____
WIND MPH _____ INSOLATION _____ SOIL TEMP _____
SAMPLE TYPE: ANALYSIS TYPE AND RESULTS
GROUND PROBE _____
CORE HOLE _____
SOIL HEADSPACE _____
PERMANENT PORT _____
OTHER (DESCRIBE) _____
NOTES: (SOIL DESCRIPTION, UNUSUAL CONDITIONS, ETC.)

SAMPLE POINT_____ DATE, TIME _____
AMBIENT TEMP _____ HUMIDITY _____ BAR. PRESS._____
WIND MPH _____ INSOLATION _____ SOIL TEMP _____
SAMPLE TYPE: ANALYSIS TYPE AND RESULTS
GROUND PROBE _____
CORE HOLE _____
SOIL HEADSPACE _____
PERMANENT PORT _____
OTHER (DESCRIBE) _____
NOTES: (SOIL DESCRIPTION, UNUSUAL CONDITIONS, ETC.)

Figure 44. Field form for soil vapor sampling

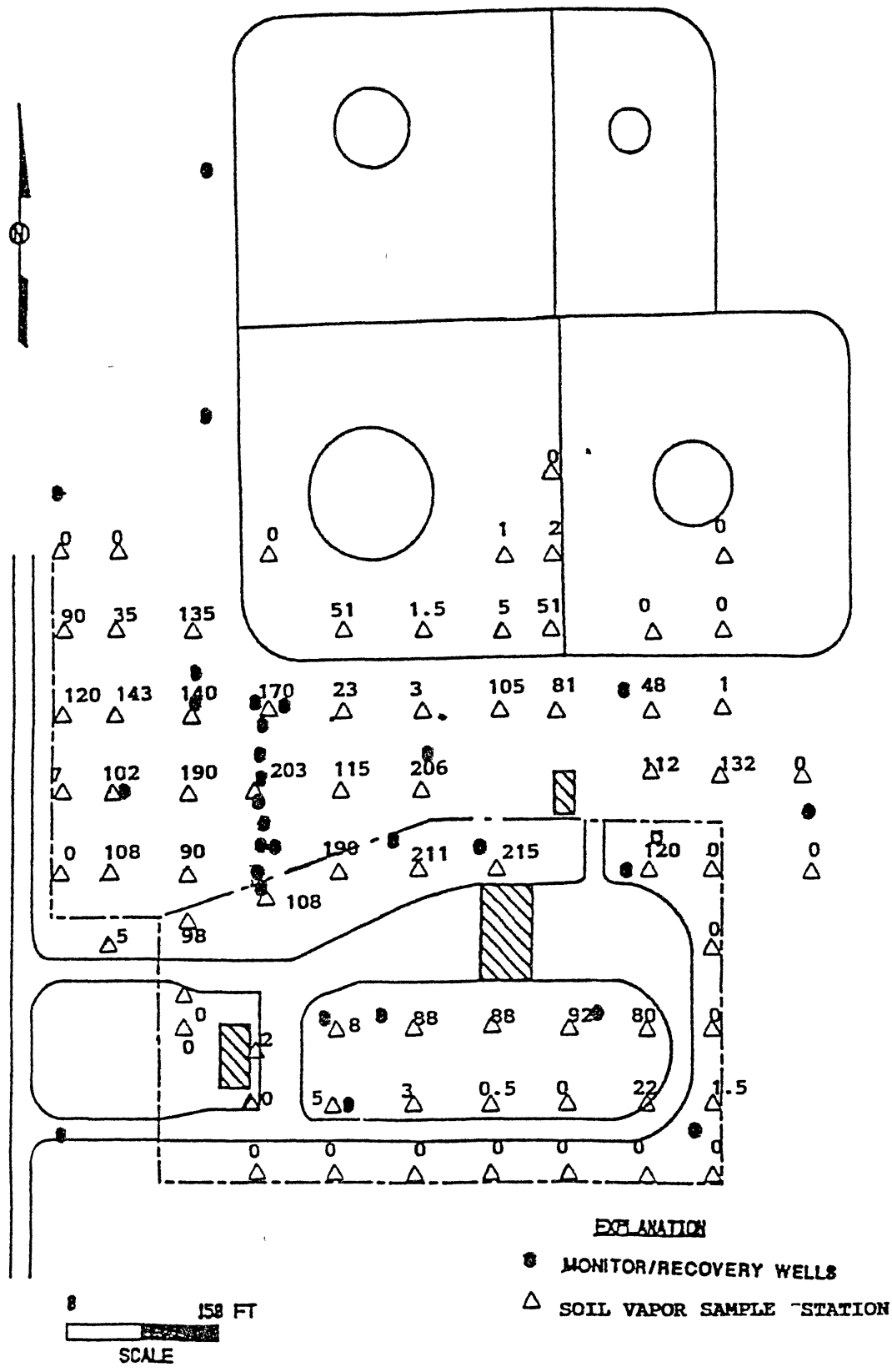


Figure 45. TIV values from soil vapor survey; depth 3 feet

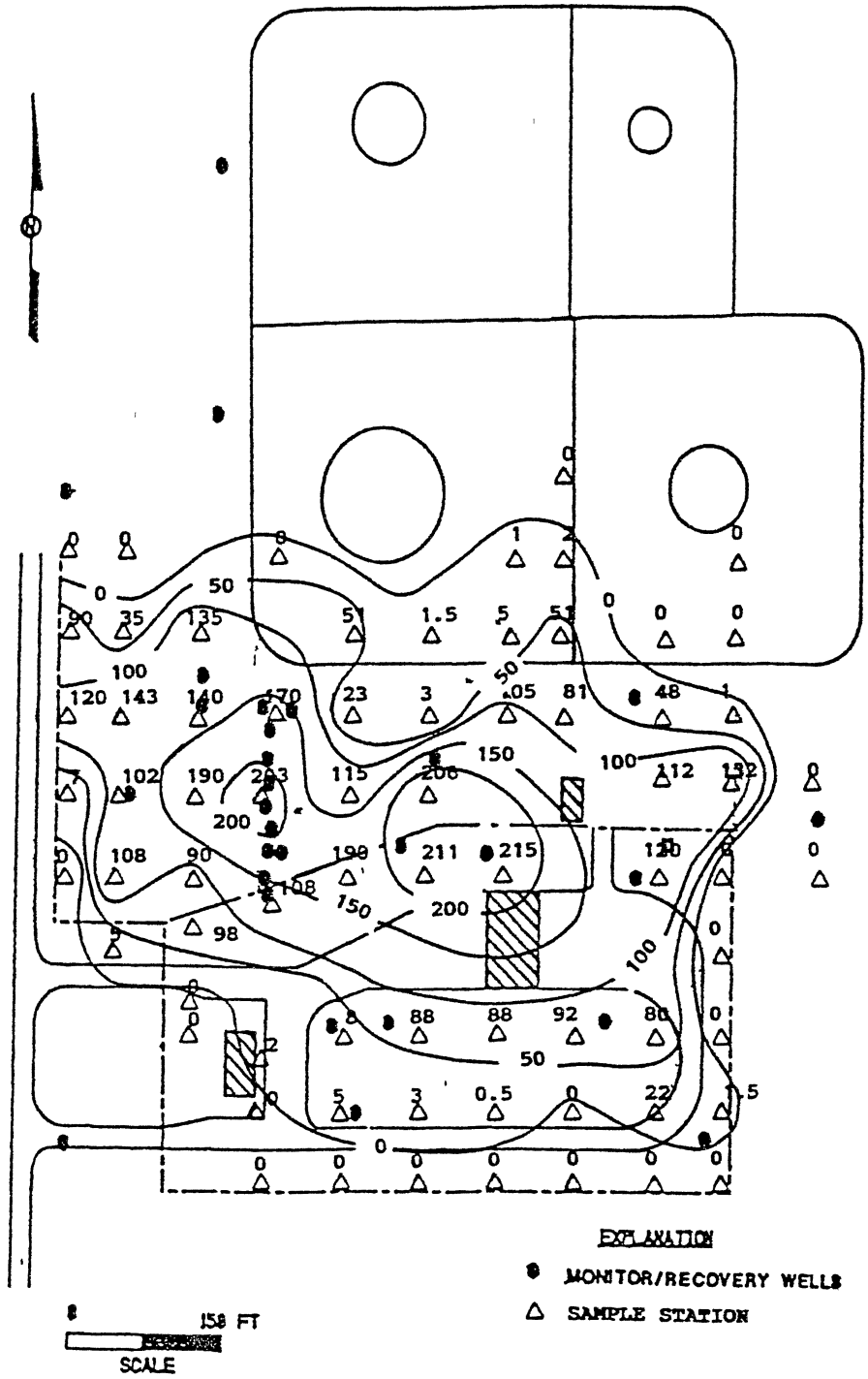


Figure 46. Soil vapor isoconcentration map, 12/10/90

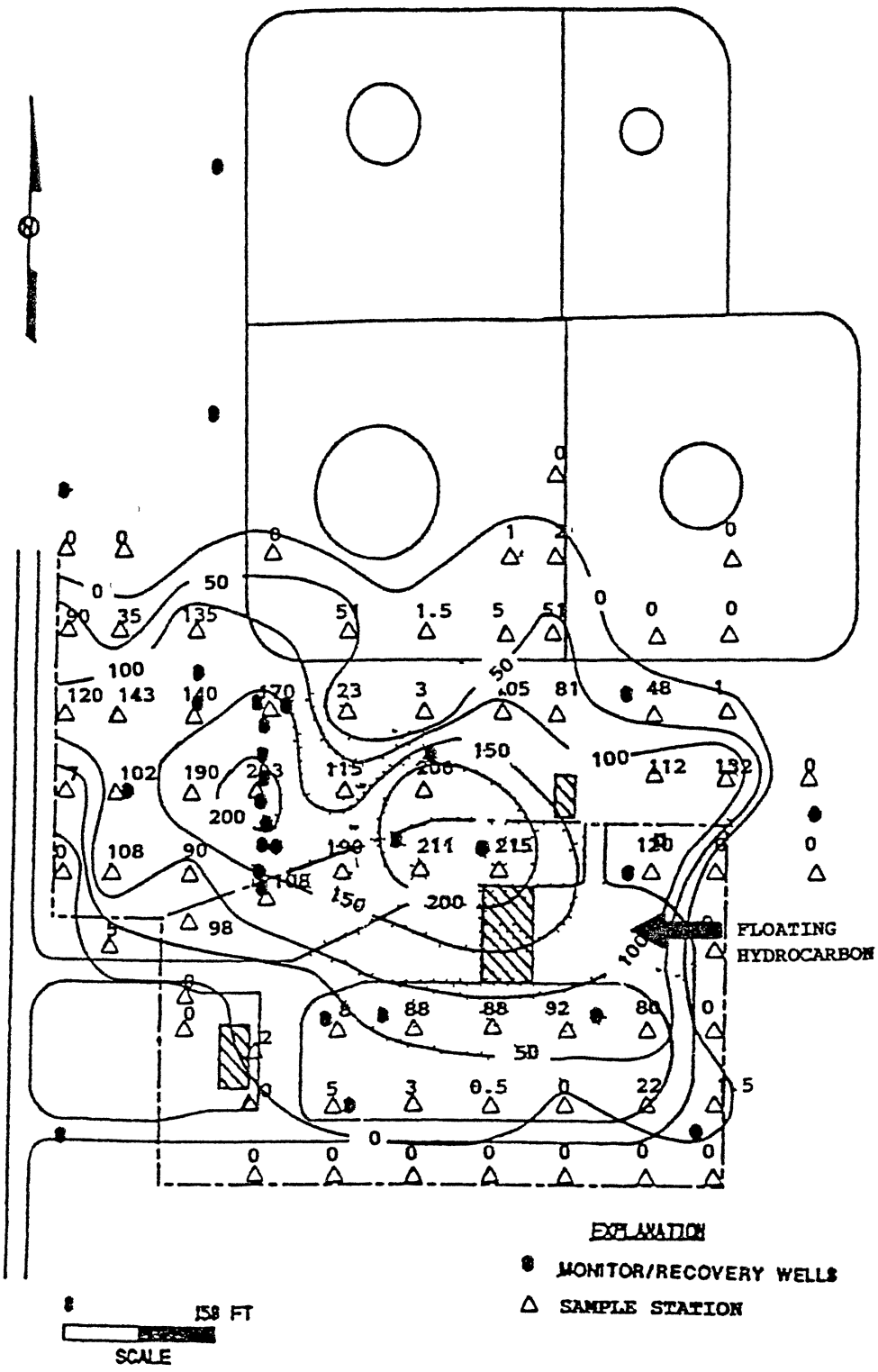


Figure 47. Soil vapor isoconcentration map with free product plume, 12/10/90

at the site as defined by ground water monitoring wells. The highest soil vapor concentrations correlate roughly with the extent of free product occurrence; however the area of high soil vapor concentration extends to the west-northwest far beyond the free product plume. In the following section reasons for this "skewed" pattern of high soil volatile organic vapor concentration are discussed, based on interpretation of hydrogeologic data from the site.

Hydrogeologic Interpretation of Soil Vapor Survey

Effects of Depth to Phreatic Fluid

Figure 48 is a map of depth to fluid across the site during the time the soil vapor survey was conducted. As shown by this figure, the depth to phreatic fluid decreases to the northwest and along the ephemeral stream bed to the north of the truck loading area, as shown by Figure 9, the site topographic map (page 42). Apparently because of the more shallow ground water in this area, the soil vapor concentration is higher at three feet below surface.

Aquifer Texture Effects

Figure 49 is a map of the aquifer material grain size classification at the depth of water table residence for the area. As this map shows, the soil becomes much more

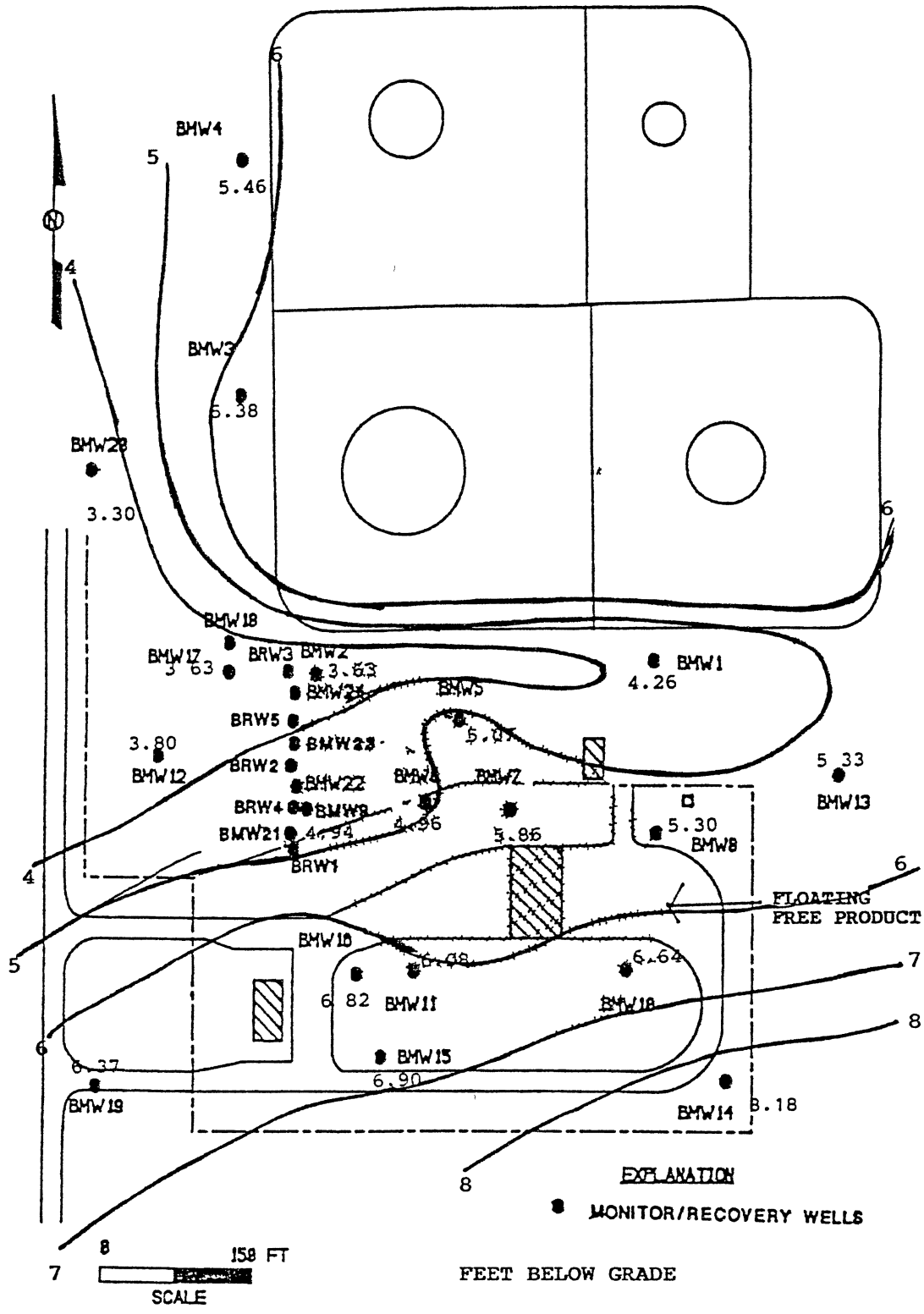


Figure 48. Depth to phreatic fluid, 12/12/90

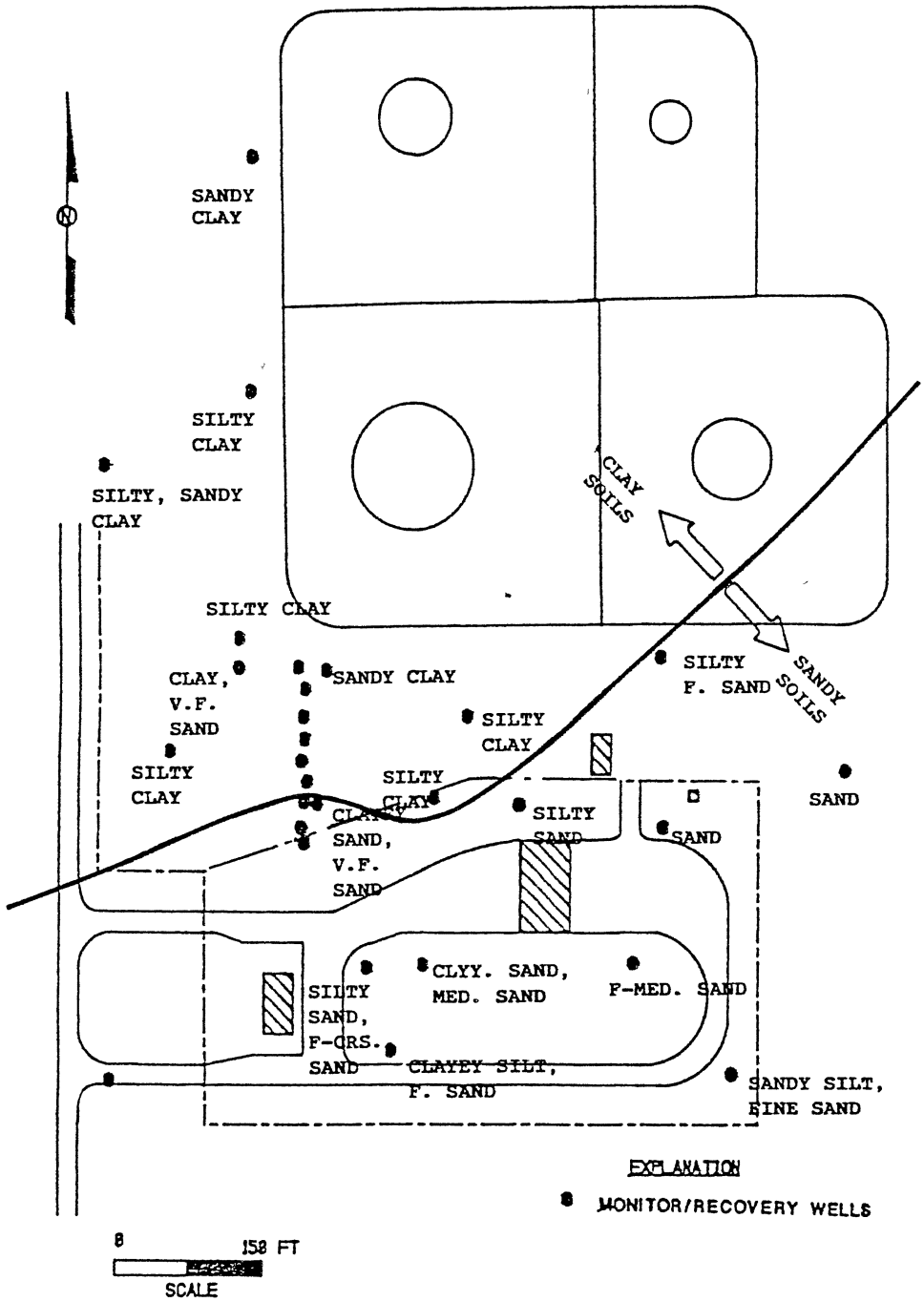


Figure 49. Grain size category at water table residence depth

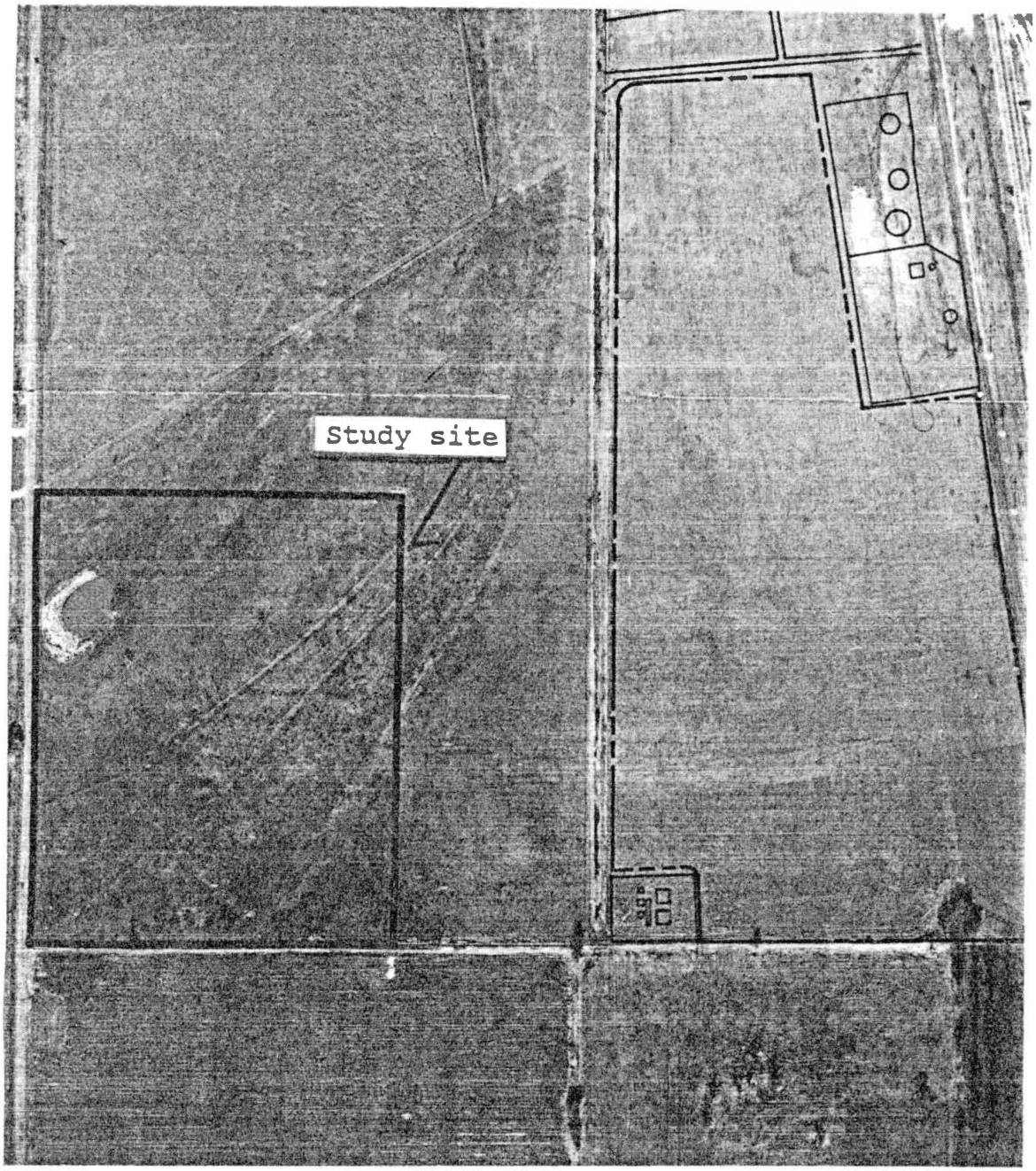


Figure 50. Aerial photograph of study site before construction of facility

fine-grained to the north of the truck loading area, just south of the ephemeral stream bed which runs between the truck loading area and the storage tanks. Figure 50 is an aerial photograph of the area before the bulk fuel loading facility was constructed. As seen in this photo, the eastward-convex arcuate lineaments indicate that the area lies in a former meander channel of the Washita River. The clay soils encountered in the northwest portion of the study area are apparently channel fill sediments deposited after the stream meander left this course. These fine-grained soils would be expected to inhibit the movement of organics by their higher adsorption rates and by slowing ground water flow. However as based on comparison of the spatial distribution of different soil texture and the soil vapor concentration map, the aquifer grain size appears to have had little effect on the measured soil vapor concentration distribution.

Topographic Effects

The area of higher volatile concentration to the west of the free oil plume appears to be separated from the free oil plume by an area of lower concentration, as if it were from another source. There is no apparent source of hydrocarbons at this location; however an explanation may be found in the water table elevation records for the site. Depth to ground water and free oil elevations have been recorded at the site since March, 1989. Figure 9, the site

topographic map (page 42), shows a small intermittent stream which flows westward, in between the tank dikes to the north, and the truck loading area to the south. Several monitor wells lie very near this drainage pathway. In May, 1990, record rainfall occurred in the area, and ground water, as measured in the monitor wells, rose to unprecedented highs. Figure 51 is a hydrograph showing depth to ground water and free oil in well BMW5. This graph shows that floating product in BMW5 was very near surface during this period. Figure 52 is a map of elevation of the top of ground water and floating product measured in monitor wells on May 22, 1990, superimposed on the topographic map of the area. As shown on this map, the ephemeral stream that flows through the area was apparently in a gaining condition during this period, and the gasoline floating on ground water around well BMW5 flowed from the ground into the stream. This stream bed runs into a nearly enclosed depression at the western edge of the property before emptying into the ditch along the side of the road. This depression apparently acted to trap the gasoline floating in the stream, and it accumulated in this area, percolating into the soil when the water table later descended. This trapped floating gasoline was apparently the source for the higher concentration of volatiles measured in the soil vapor in this area.

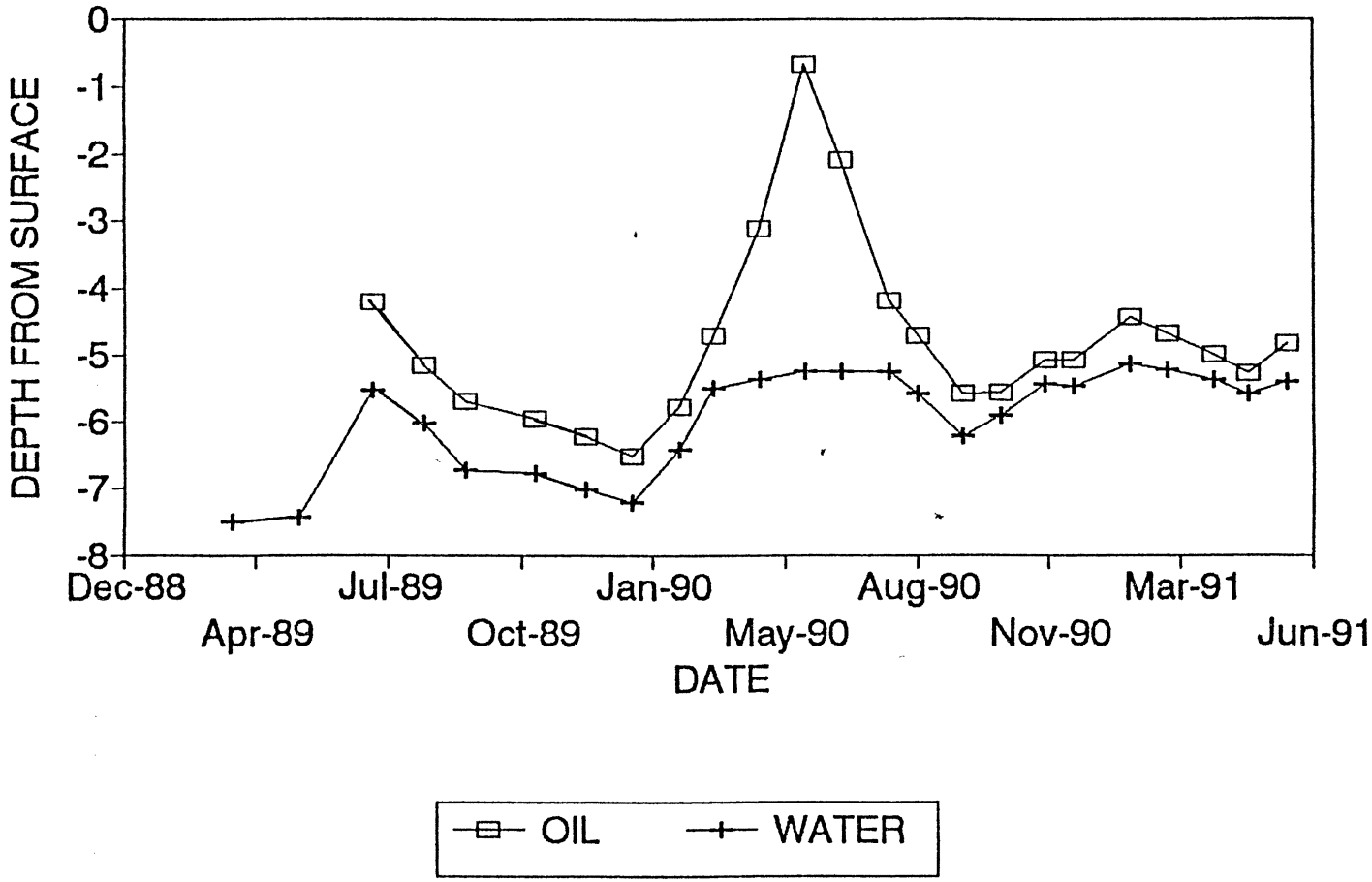


Figure 51. Hydrograph of BMW5, March 1989 to June 1991

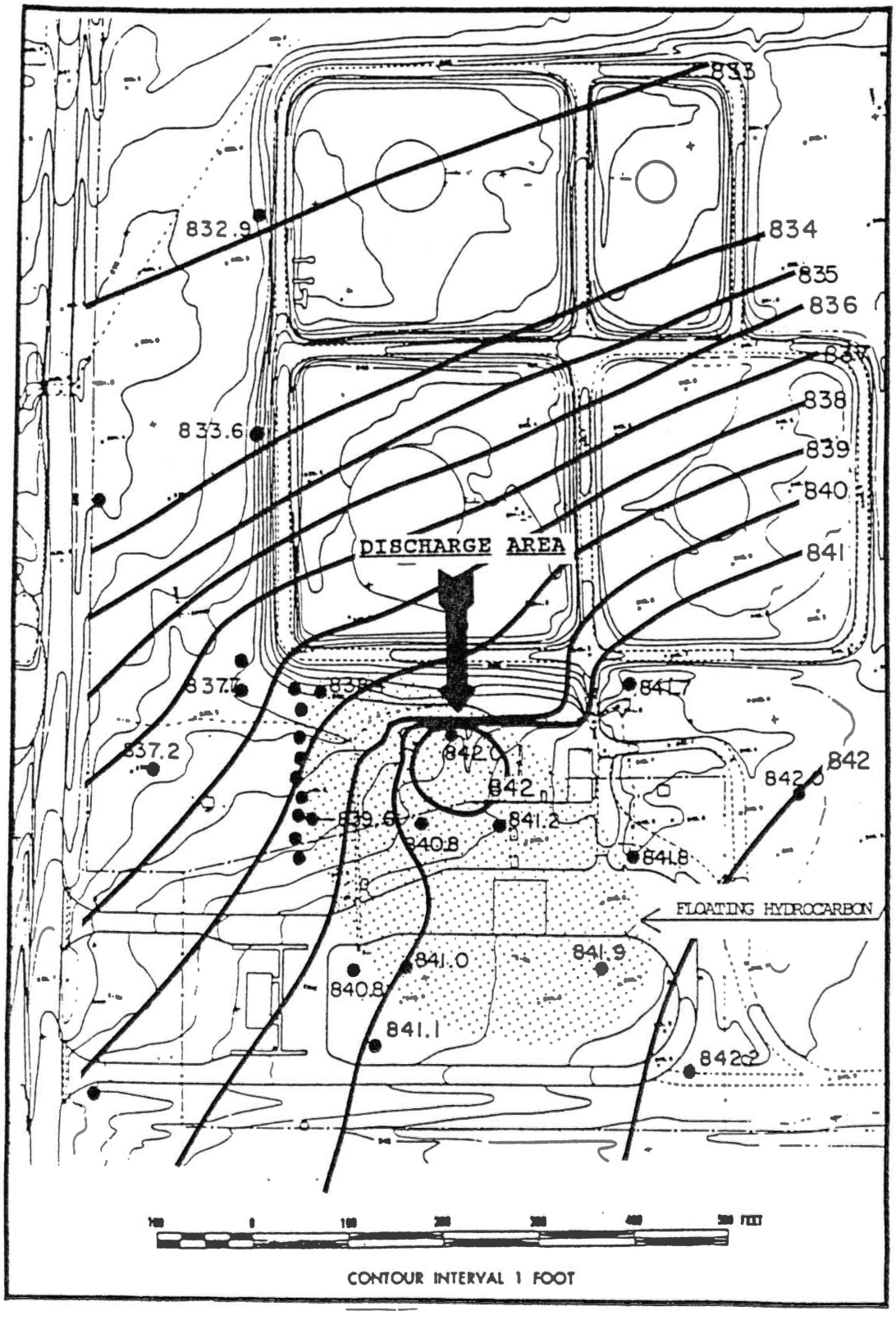


Figure 52. Phreatic fluid elevation superimposed on topographic map, 5/22/90

Comparison of Soil Vapor Survey Results to Ground Water Sample Analyses

To better define the source of the measured soil volatile organic vapor concentration, ground water was sampled from several of the monitor wells and analyzed for the gasoline-related volatile hydrocarbons benzene, toluene, ethylbenzene and xylene. Analyses from past sampling events at the site were also included to construct a map showing total BTEX concentration in ground water, included as Figure 53. (Analytical data are included in Appendix D, sorted by date). Figure 53 shows a west-northwestward trend of high volatile concentrations very similar to that measured in the soil vapor, shown by Figure 46. Figure 21, a potentiometric surface map of the area, shows that ground water flows to the northwest across the area, which is the general direction in which the high volatile organic vapor concentration is skewed both in the soil vapor and ground water. Volatile components from the leaked product have dissolved in and flowed with the ground water faster than the free product itself has moved from the source. The very good agreement between the soil vapor survey TIV concentration and the ground water BTEX maps indicates that the soil vapor survey delineated the extent of volatile organic impact to ground water with a fair degree of accuracy. The difference in depth to fluid across the site, as shown by Figure 48, appears to have had

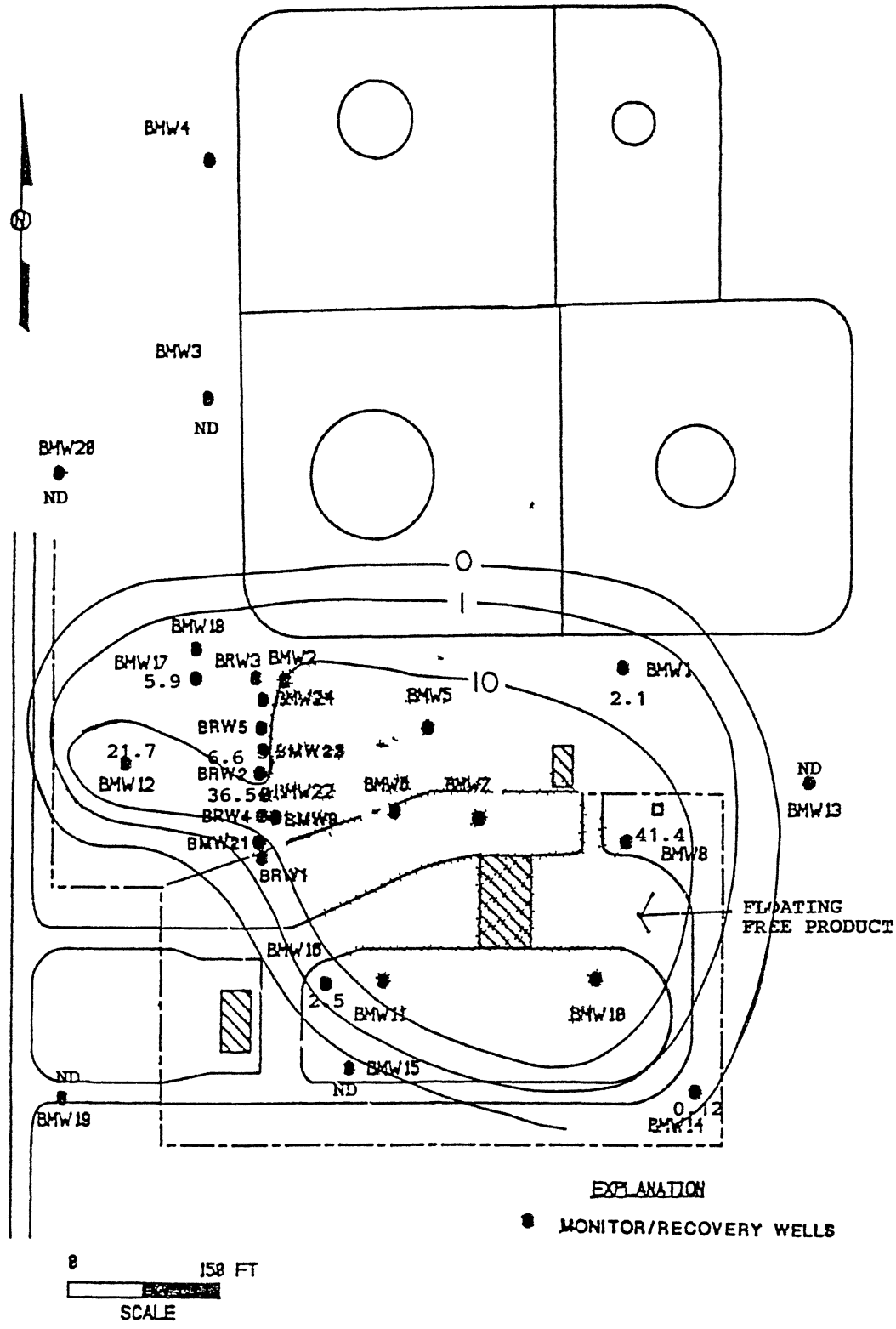


Figure 53. Isoconcentration map, total BTEX in ground water, mg/l

some influence on the soil vapor concentrations measured by the PID, as indicated by the high readings at the northwest corner of the surveyed area, where the depth to ground water is least. The water samples indicate a contrasting decrease in concentration in this area.

In order to determine whether the soil vapor concentrations from the survey provided a correlative indication of the absolute concentration of volatile organics in ground water, the total ionizable vapor concentration in soil was interpolated above each location where ground water was sampled, for comparison of the two values. A graph of the interpolated soil vapor TIV vs ground water BTEX is presented as Figure 54. As shown by this graph, the soil vapor TIV concentrations are all higher than total BTEX concentration in the ground water, and the plot does not approximate a line. Thus it does not appear to be possible to translate soil vapor concentration to ground water BTEX concentration, at least when using the PID. This is not surprising, since the PID responds to all ionized vapors; any vapor present with ionization potential below or near 10.0 electron-volts would produce a response with the PID. Since the PID is calibrated to only one standard, and responds differently to different vapors, it is not possible to establish a numerical relationship to total BTEX measurements. Also the concentration of volatiles in ground water is affected to a far lesser degree by the constantly changing environmental variables

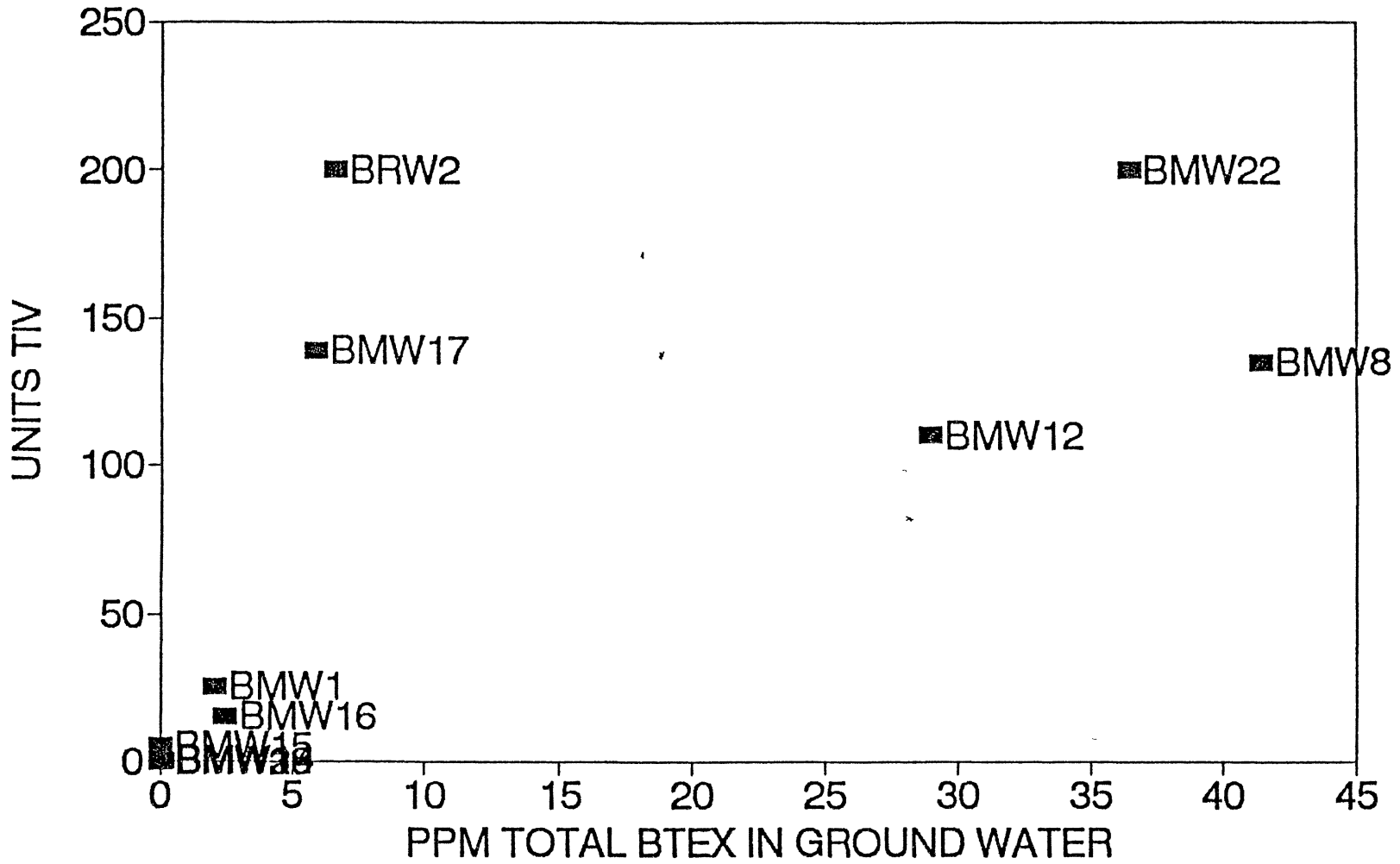


Figure 54. Scatter plot, interpolated units TIV in soil vapor vs BTEX in ground water

which may affect soil vapor concentration. The areas of highest soil TIV concentration do, however, correlate with the areas of highest BTEX concentration (or free product) in ground water. Therefore, at this site, volatile organic vapor in soil, as measured by the photoionization detector, is a reliable indicator of the presence of volatile organic contamination in ground water, and provides a less reliable indicator of their concentration.

In addition to confirming the findings of the soil vapor survey, the ground water sample analyses provide information pertaining to the behavior of the volatile organic chemicals in ground water at the site. The percentage of each BTEX constituent in total BTEX was calculated, and areas of equal percentage were mapped for each component. These maps are presented as Figures 55 through 58. In general, the wells closest to the free product plume have the highest total BTEX concentration, as shown by Figure 53; however the percentage of benzene in BTEX is highest in the area in front of the plume, and lowest behind it, as shown by Figure 55. The percentage of toluene is distributed in a pattern closely resembling that of the floating hydrocarbon, without much contrast in the up-gradient versus down-gradient percentages (Figure 56). Conversely, the Xylenes are by far the major component in those wells located behind the area of free product occurrence, as shown by Figure 58; these wells also have the lowest total BTEX concentration. Ethylbenzene is a

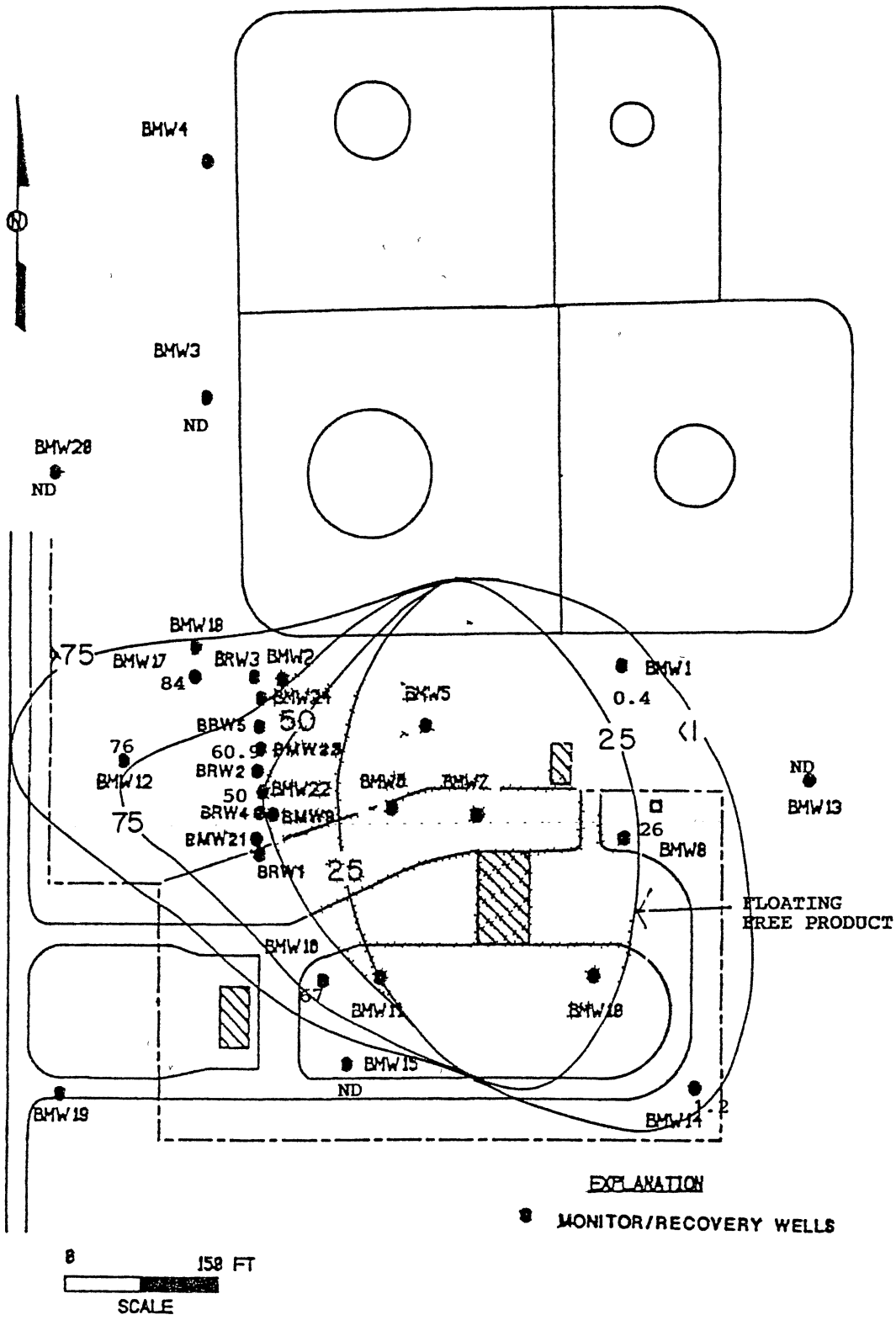


Figure 55. Percentage distribution map: percent benzene in total BTEX in ground water

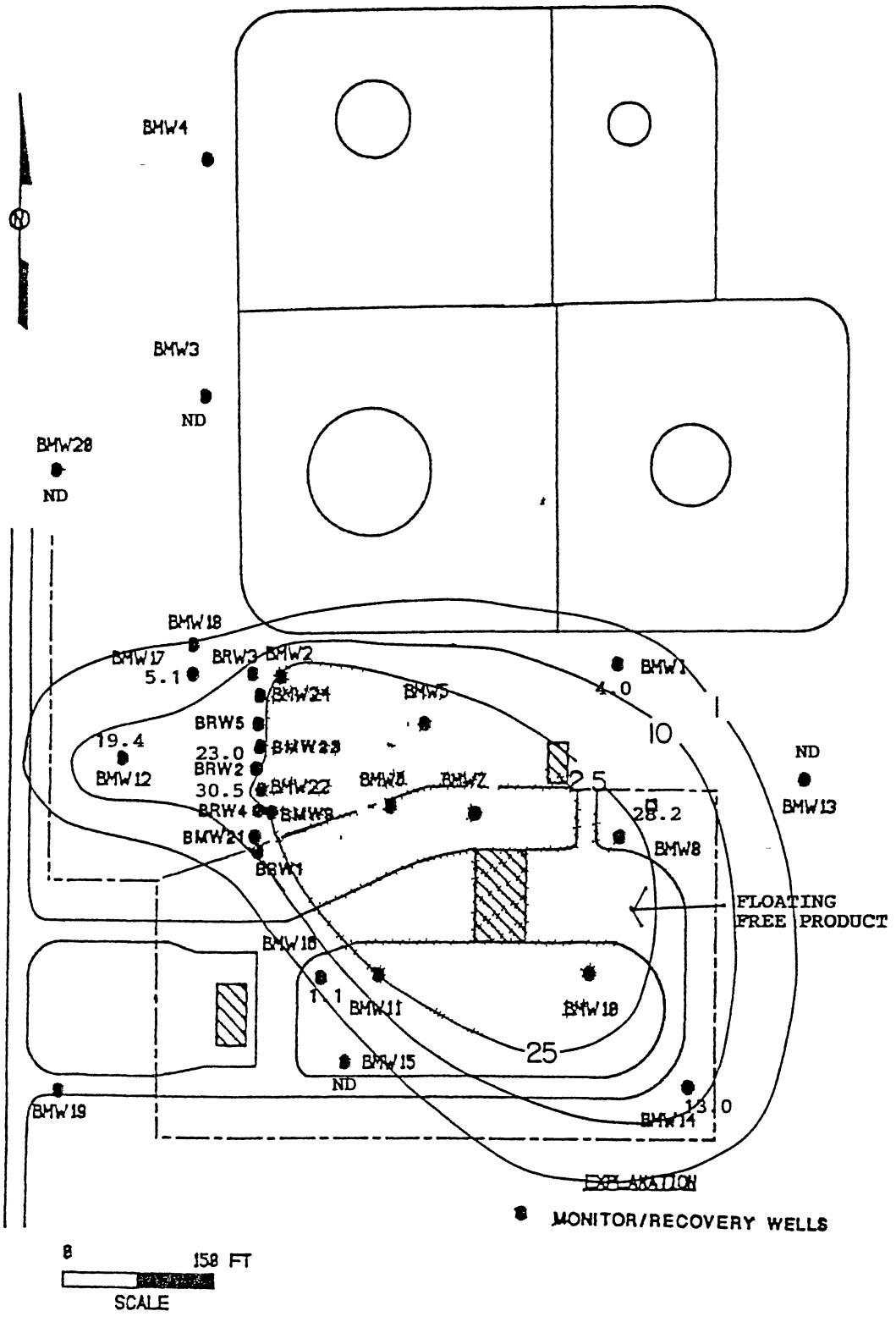


Figure 56. Percentage distribution map: percent toluene in total BTEX in ground water

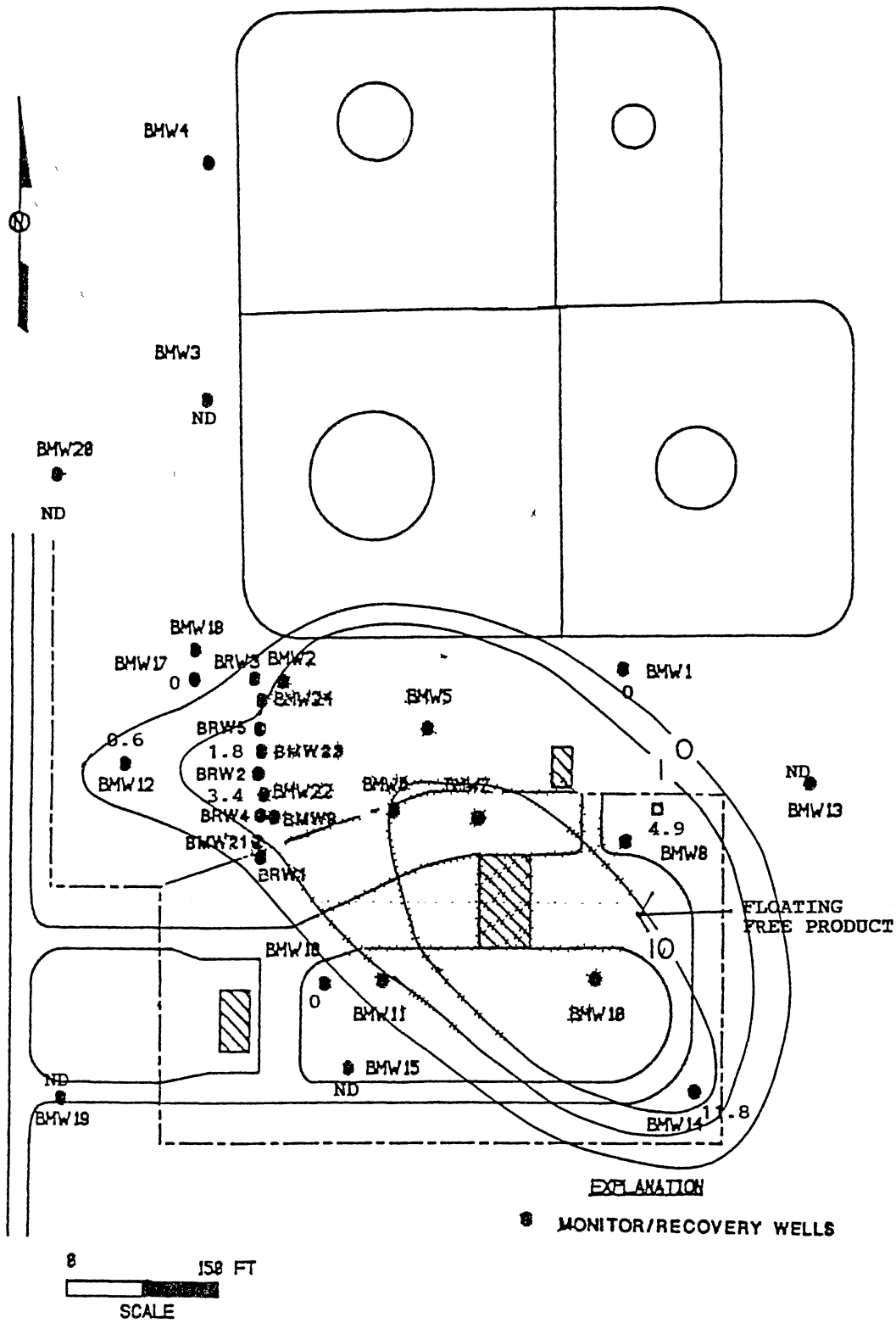


Figure 57. Percentage distribution map: percent ethylbenzene in total BTEX in ground water

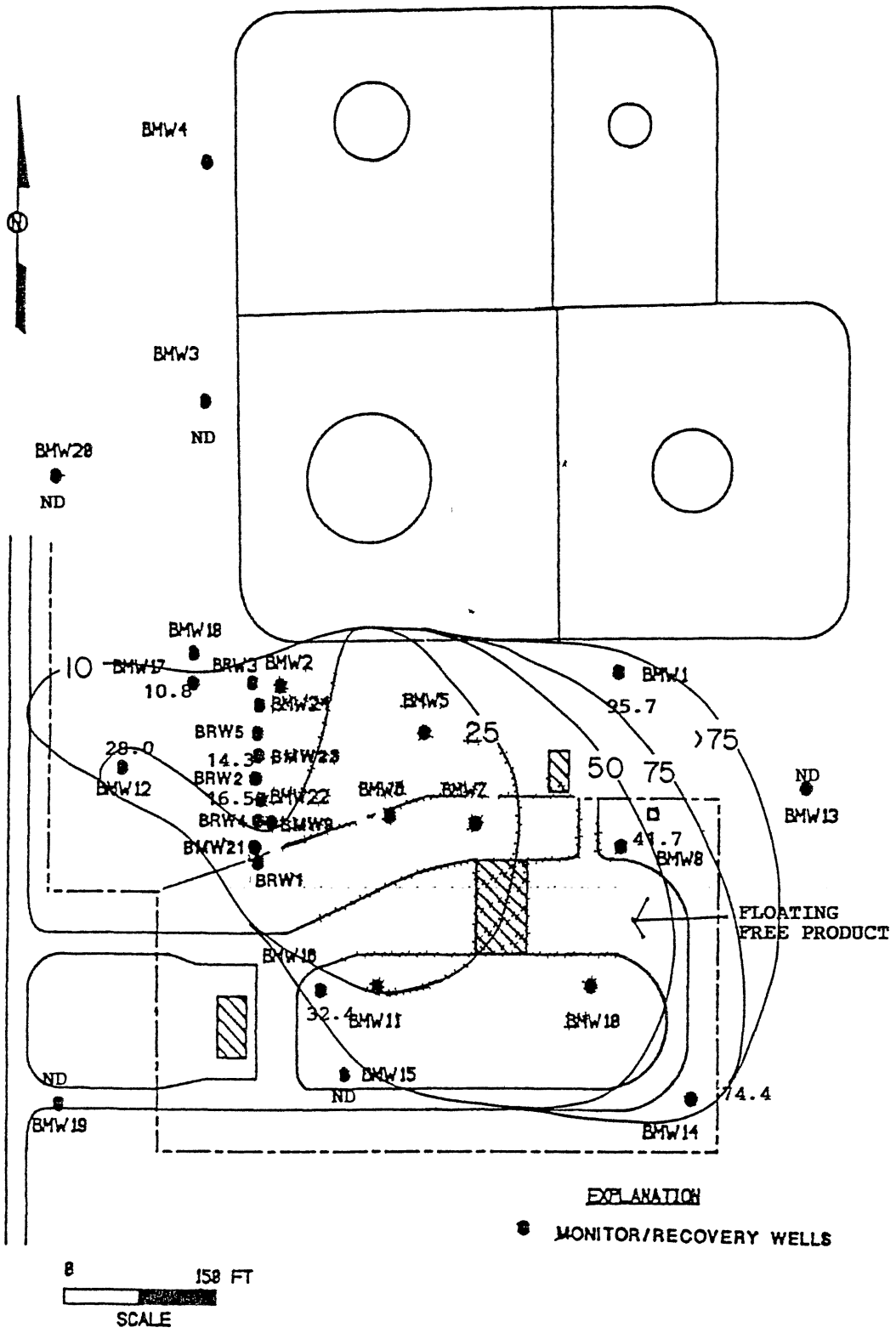


Figure 58. Percentage distribution map: percent xylenes in total BTEX in ground water

minor constituent compared to the other components; it also shows a percentage distribution that is slightly skewed towards the up-gradient portion of the plume (Figure 57).

The relative distribution patterns of these chemical species is directly related to their solubility and soil/water partition coefficient, K_{OC} (organic carbon partition coefficient). These indices are essentially an inverse function (Griffin and Roy, 1985). Figure 59, from McKay and Shiou, 1981, and Figure 60, from Griffin and Roy, 1985, list physicochemical properties for BTEX components. Benzene, being the most soluble by far with a solubility of approximately 1781 g/m^3, and with the lowest K_{OC} value, approximately 97 g/m^3, has traveled the furthest with ground water flow, and is nearly all leached from the up-gradient area of the plume. Toluene is next, with solubility of approximately 537, with medium mobility (K_{OC} = 242), and has separated slightly toward the front of the plume. Ethylbenzene and the xylenes display similar solubilities (167 and 176, respectively) and are the least soluble of the BTEX components. They also display the highest tendency to adsorb to soils, as indicated by their higher K_{OC} values (477 average for m,o and p-xylene, from Griffin and Roy, 1985). As may be predicted by these properties, at this site the xylenes and ethylbenzene have apparently adsorbed to the soil and remained in place, while the highly soluble benzene has traveled rapidly down-gradient with ground water flow, and the moderately soluble

Compound	MW	mp, °C	bp, °C	Vapor pressure p_s, kPa *	Solubility S, g/m^3	Henry's law constant kPa m^3/mol* calc	expt1	recom
Data at 25°C for monoaromatics								
Benzene	78 11	5 53	80 1	12 7	1780	0 557	0 562	0.550± 025
					1755	0 565		
					1769	0 561		
					1790	0 554		
					1779 5	0 557		
					1740	0 570		
					1869	0 533		
					1770	0.560		
Toluene	92.13	-95	110 6	3 80	515	0 68	0 673	0.670± 035
					517	0 677		
					544	0 632		
					534 3	0 655		
					500	0 70		
					519 5	0.674		
					627	0 558		
Ethyl-benzene	106 2	-95	136.2	1 27	152	0 887	0 854	0.80± 07
					177	0 762		
					131	1 03		
					208	0 648		
					161	0 837		
					175	0 771		
p-Xylene	106.2	13 2	138	1.17	185	0 671		0.710± 08
					198	0 628		
					157	0 791		
					156	0 797		
					200	0 621		
m-Xylene	106 2	- 47 9	139	1 10	162	0 721		0 700±0.10
					196	0.596		
					173	0.675		
					146	0.80		
					134	0.872		
o-Xylene	106 2	- 25 2	144 4	0.882	175	0 535		0 50±0 06
					170.5	0 549		
					167	0.561		
					204	0 459		
					213	0.440		

Figure 59. Physicochemical properties of BTEX compounds, from McKay and Shiou, 1981

Soil-water partition coefficients (K_{oc}) for 37 organic solvents and their mobility classification.

Solvent	log K_{oc} (from solubility)	log K_{oc} (from K_{ow})	Mean K_{oc}	Mobility Classification
1. Acetone	—[a]	0.015	1	very highly mobile
2. Benzene	1.93	2.01	97	highly mobile
3. n-Butyl alcohol	0.94	1.02[b]	10	very highly mobile
4. Carbon disulfide	1.80	—[b]	63	highly mobile
5. Carbon tetrachloride	2.15	2.44	232	medium mobility
6. Chlorobenzene	2.31	2.57	318	medium mobility
7. o-Dichlorobenzene	2.62	3.06	898	low mobility
8. m-Cresol	1.26	1.55	27	very highly mobile
9. o-Cresol	1.23	1.24	17	very highly mobile
10. p-Cresol	1.29	1.27	19	very highly mobile
11. Cyclohexanone	1.04	0.96	10	very highly mobile
12. Ethyl acetate	0.89	0.91	8	very highly mobile
13. Ethyl benzene	2.60	2.87	622	low mobility
14. Diethyl ether	0.99	0.96	9	very highly mobile
15. Isobutyl alcohol	0.89	0.92	8	very highly mobile
16. Methanol	—[a]	-0.23[b]	<1	very highly mobile
17. Methylene chloride	1.40	—[b]	25	very highly mobile
18. Methyl ethyl ketone	0.58	0.55	4	very highly mobile
19. Methyl isobutyl ketone	1.30	1.42	24	very highly mobile
20. Nitrobenzene	1.90	1.79	67	highly mobile
21. Pyridine	—[a]	0.84	7	very highly mobile
22. Tetrachloroethylene	2.60	2.41	303	medium mobility
23. Trichloroethylene	2.09	2.22[b]	152	medium mobility
24. 1,1,1-Trichloroethane	2.19	—[b]	155	medium mobility
25. Toluene	2.28	2.43	242	medium mobility
26. m-Xylene	2.56	2.91	588	low mobility
27. o-Xylene	2.56	2.55	363	medium mobility
28. p-Xylene	2.56	2.87[b]	552	low mobility
29. Trichlorofluoromethane (F-11)	2.68	—[b]	479	medium mobility
30. 1,1,2-Trichloro-1,2,2-trifluoroethane (F-113)	2.57	—[b]	372	medium mobility
31. Chlorodifluoromethane (F-22)	1.79	—[b]	62	highly mobile
32. Dichlorofluoromethane (F-21)	1.48	—[b]	30	very highly mobile
33. Dichlorodifluoromethane (F-12)	2.43	—[b]	269	medium mobility
34. Chloropentafluoroethane (FC-115)	2.85	—[b]	708	low mobility
35. 1,2-Dichlorotetrafluoroethane (F-114)	2.64	—[b]	437	medium mobility
36. 1,1,1,2-Tetrachloro-2,2-difluoroethane (R-112a)	2.71	—[b]	513	low mobility
37. 1,1,2,2-Tetrachloro-1,2-difluoroethane (F-112)	2.66	—[b]	457	medium mobility

[a] miscible in water [b] no n-octanol data known

Figure 60. Physicochemical properties of BTEX compounds, from Griffin and Roy, 1985

toluene has shown much less segregation from the floating product plume.

A "fresh" gasoline spill would not be expected to display this degree of separation of chemical components, yet a very old spill would not be expected to have such high concentrations of BTEX compounds, which are readily degraded in the subsurface, as indicated on Figure 61, (Jamison, et al, 1975), which shows relative degradation rates for gasoline constituents. The spatial variation of percentage distributions of BTEX components seen here is an illustrative example of how the age of a spill may be identified by a detailed soil vapor survey, and also of the importance of using the highest degree of sophistication possible for sample analysis during soil vapor surveys. If a gas chromatograph had been available during the soil vapor survey, a much more detailed characterization of ground water contamination at the site would have been possible by measuring organics in soil vapor. (A portable gas chromatograph was made available later in the study, and in order to simulate the results of a soil vapor survey and to evaluate the general usage of the procedure, vapor samples were collected from the headspace above ground water or floating product in several of the monitoring wells at the site. Results are discussed in the next section).

The soil vapor survey conducted at this site is a salient example of the value of the application of soil

BIODEGRADATION OF THE COMPONENTS OF GASOLINE

Components of Sunoco 260	Initial concentration µlitre	Concentration at 192 hr. µlitre		Percent biodegraded over and above control
		Control	Sample	
n-Propane	Trace	Trace	Trace	0
n-Butane	0.63	0.37	0.37	0
n-Pentane	0.55	0.25	0.06	70
n-Hexane	1.36	0.78	0.15	46
n-Heptane	0.37	0.20	Trace	49
n-Octane	0.34	0.18	Trace	54
Olefins-C_4	0.11	0.18	0.12	0
Olefins-C_5	1.04	0.30	0.14	16
Olefins-C_6	0.51	0.16	0.07	18
Isobutane	0.11	0.13	0.12	0
Cyclopentane	0.17	0.05	0.04	0
Cyclohexane	0.12	0.06	Trace	45
Methylcyclopentane	0.41	0.18	0.14	10
Methylcyclohexane	0.05	0.04	Trace	75
2-Methylbutane	3.29	1.34	1.31	0
2-Methylpentane	1.72	0.83	0.73	6
3-Methylpentane	1.30	0.56	0.47	7
2-Methylhexane	0.74	0.53	0.36	23
3-Methylhexane	0.66	0.37	0.48	0
2-Methylheptane	0.35	0.15	Trace	38
3-Methylheptane	0.46	0.31	0.10	45
4-Methylheptane	0.15	0.08	Trace	48
2,2-Dimethylbutane	0.28	0.16	0.09	25
2,3-Dimethylbutane	0.86	0.37	0.36	0
2,2-Dimethylpentane	0.42	0.19	0.15	9
2,4-Dimethylpentane	0.53	0.31	0.25	11
3,3-Dimethylpentane	0.04	0.02	Trace	45
2,3-Dimethylpentane	0.48	0.24	0.21	0
2,5-Dimethylhexane	0.53	0.33	0.22	20
2,4-Dimethylhexane	0.46	0.22	0.20	0
2,3-Dimethylhexane	0.54	0.29	0.19	19
3,4-Dimethylhexane	0.09	0.08	Trace	84
2,2-Dimethylhexane	0.05	0.04	Trace	75
2,2-Dimethylheptane	0.09	0.06	Trace	62
1,1-Dimethylcyclopentane	0.12	0.04	Trace	25
1,2 and 1,3-Dimethylcyclopentane	0.12	0.10	Trace	78
1,3 and 1,4-Dimethylcyclohexane	0.02	Trace	Trace	0
1,2-Dimethylcyclohexane	0.16	0.05	Trace	26
2,2,3-Trimethylbutane	0.03	0.02	Trace	62
2,2,4-Trimethylpentane	3.47	2.40	1.95	13
2,2,3-Trimethylpentane	0.17	0.10	Trace	54
2,3,4-Trimethylpentane	1.89	1.22	0.97	13
2,3,3-Trimethylpentane	1.97	1.35	1.02	16
2,2,5-Trimethylpentane	0.51	0.35	1.02	23
1,2,4-Trimethylcyclopentane	0.03	Trace	Trace	0
Ethylpentane	0.08	0.05	0.04	0
Ethylcyclopentane	0.11	0.04	Trace	31
Ethylcyclohexane	0.06	0.06	Trace	95
Benzene	0.41	0.45	0	100
Ethylbenzene	1.36	1.61	0	100
Toluene	2.22	2.67	0	100
o-Xylene	1.62	2.18	0	100
m-Xylene	3.28	4.29	0	100
p-Xylene	1.03	1.31	0	100
Heavy ends	8.97	11.80	1.13	87

(Jamison, et al., 1975)

Figure 61. Relative biodegradation rates for gasoline constituents, from Jamison, et al, 1975

vapor surveys to site characterization at volatile organic spill sites. The survey was completed in less than a week by one person, as compared to the completion of numerous soil borings and the installation of 20 monitoring wells to define the extent of ground water contamination. Results were immediate, requiring no lag time for laboratory sample analyses. The soil vapor survey also provided a much more dense data base (although containing less hydrogeologic information) than the soil borings and wells. Monitoring wells are necessary for definition of the absolute chemical characteristics of the contamination, and to confirm the findings of soil vapor surveys. A soil vapor survey before the installation of monitoring wells at this site would have provided valuable information with which to decide on the placement of monitoring wells. Most of the soil borings and many of the wells installed may have been omitted, thus saving a significant amount of money.

The apparent success of the "core hole" vapor sampling method in delineating hydrocarbon-impacted ground water at this site implies that it may be employed as a standard procedure in areas of low-permeability soil, as an alternative to sampling through in-situ driven probes. Further study is suggested. An indicator for the suitability of either method for a study area may be whether the soil texture is fine enough to retain an open core hole. If the hole collapses, the material is probably

coarse enough to use the in-situ probe; if not, the core hole method may be necessary.

Comparison of Monitor Well Headspace Organic Vapor Analyses with Ground Water Sample Analyses and Soil Vapor Survey Results

The vapor in selected monitor wells was sampled at 0.5 feet above fluid level and measured for volatile organic content using the OVM and the portable GC. Figure 62 is a contour map of OVM TIV concentrations from well headspace vapor, and Figure 63 is a contour map of total BTEX in well headspace vapor from portable GC measurement. The general shape of the contours are similar, yet the concentrations measured with the PID are much higher; again this is to be expected, as discussed in Chapter 4. Figures 64 through 70 are bar graphs comparing concentrations of total and individual BTEX components in ground water with well headspace vapor samples as measured by portable GC, and PID TIV. (A logarithmic scale was used on the concentration axis in order to show trace concentrations as measured in ground water). The portable GC analyses of well headspace vapor produced results rather different from the ground water analyses. Conspicuously absent from the headspace vapor samples is any detectable concentration of xylene. The reason for this discrepancy is unclear. The wells are constructed with PVC casing and screen; there may be some differential adsorption of xylene by the PVC, which would

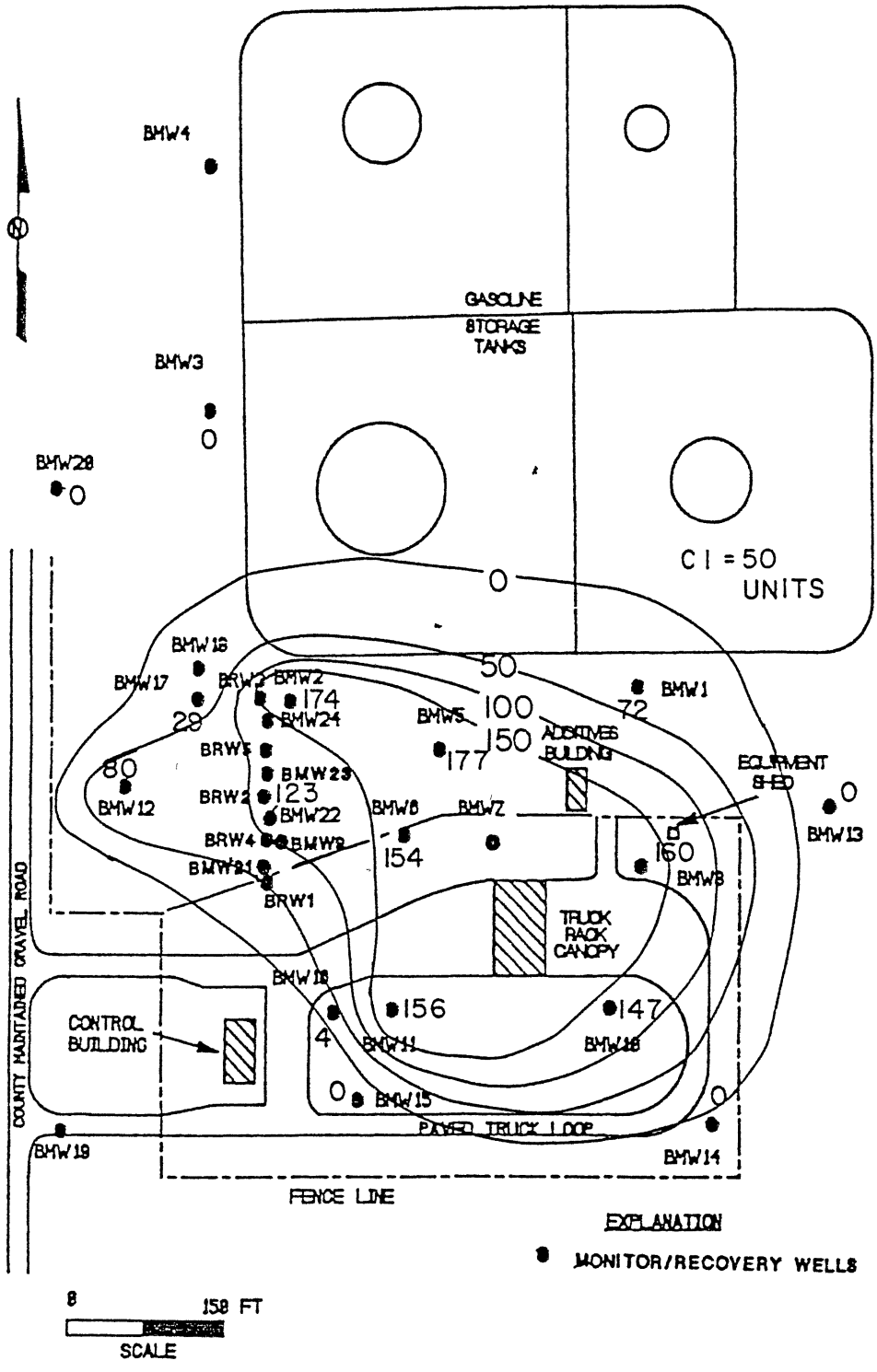


Figure 62. Isoconcentration map, TIV in well headspace

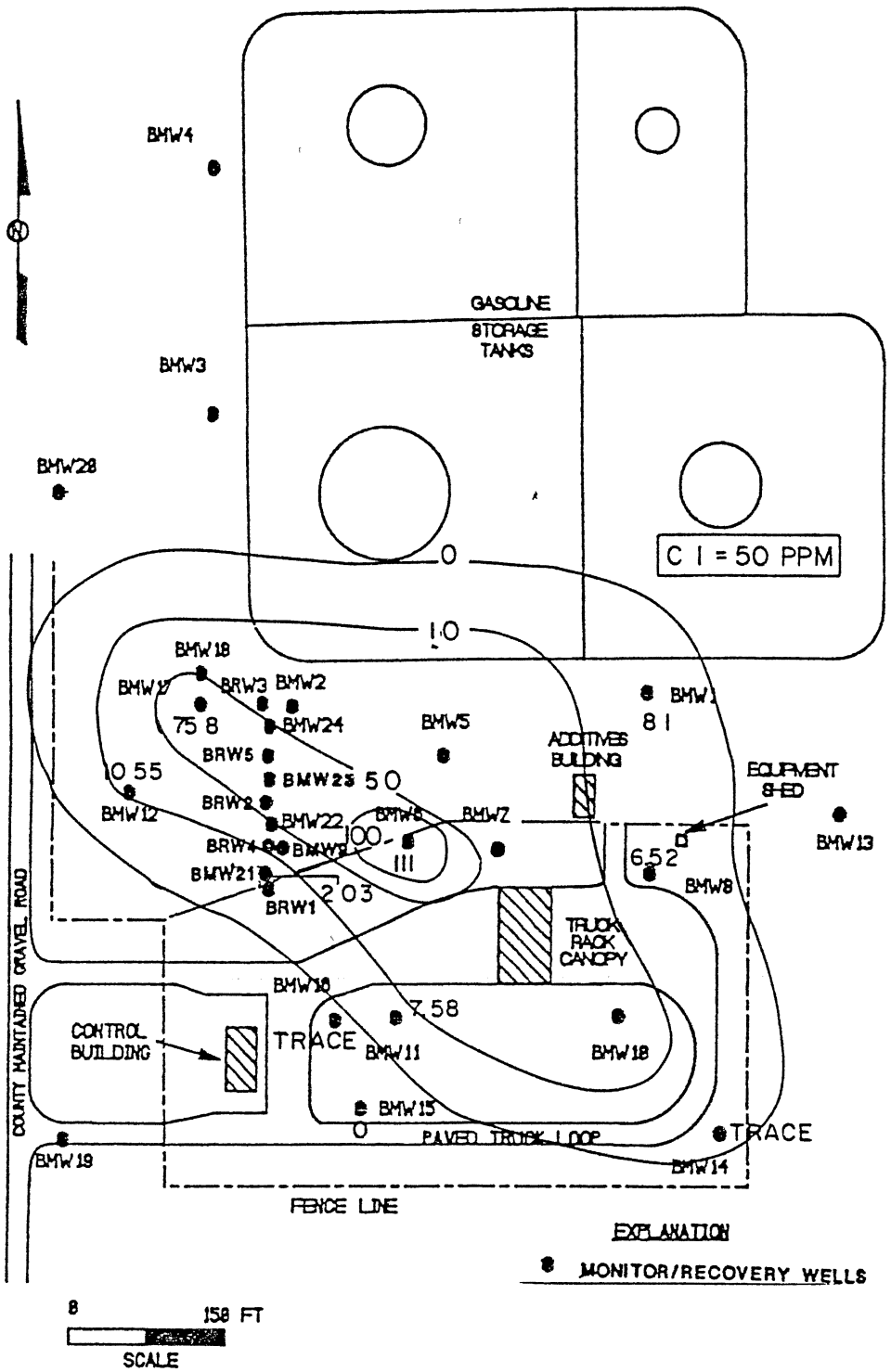


Figure 63. Isoconcentration map, total BTEX in well headspace

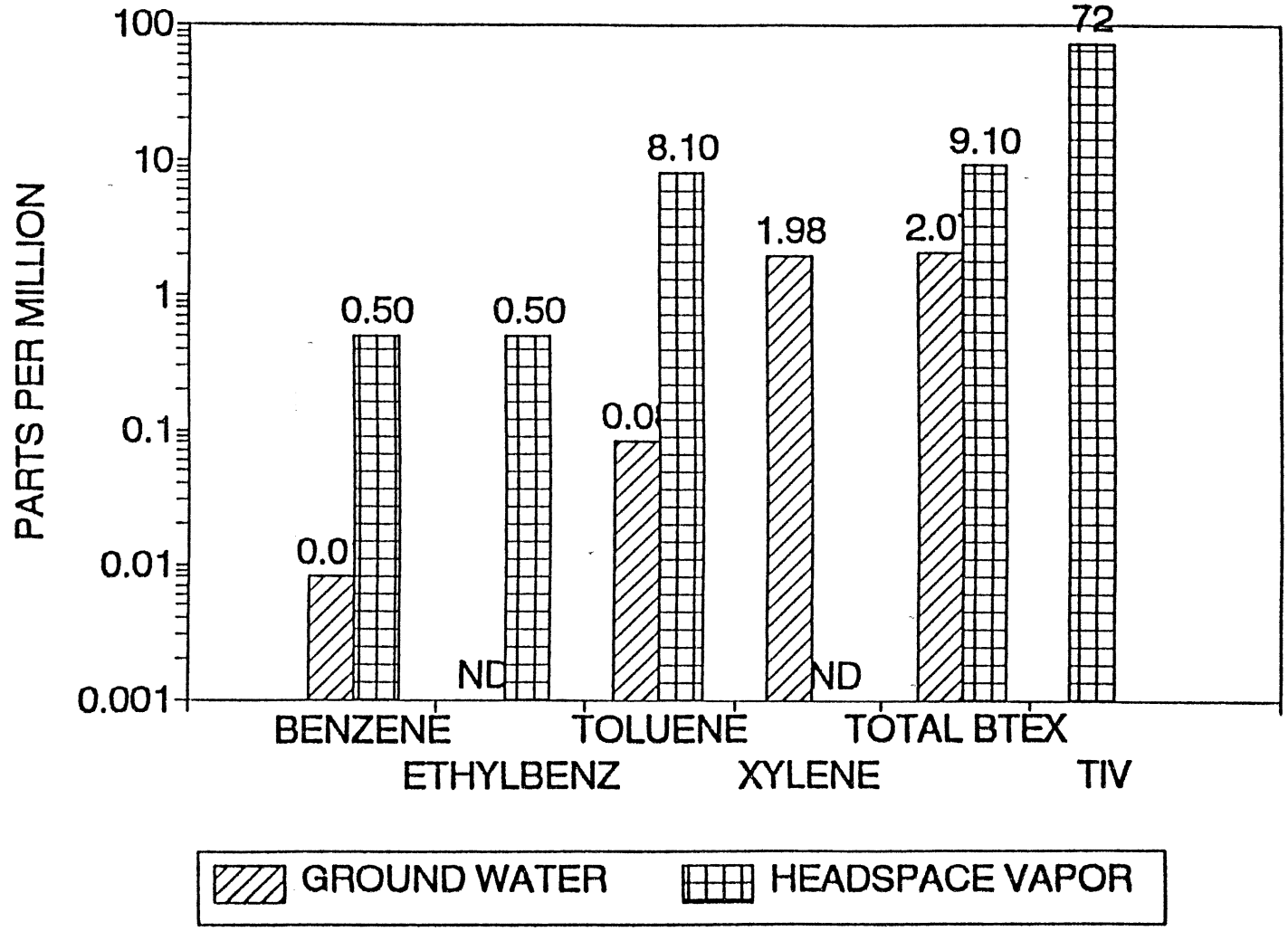


Figure 64. Bar graph comparing VOC concentrations in ground water with well headspace vapor, well BMW1

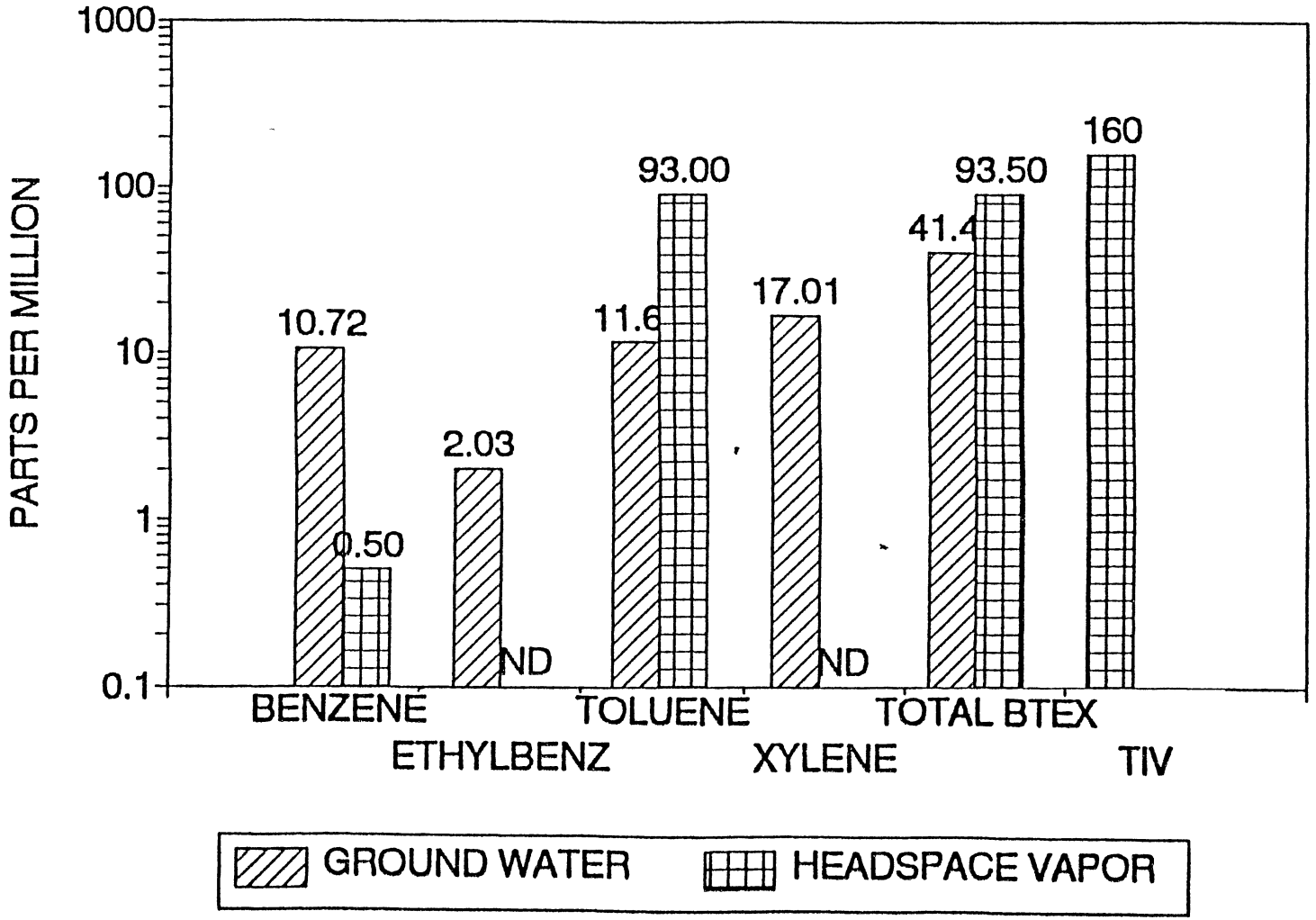


Figure 65. Bar graph comparing VOC concentrations in ground water with well headspace vapor, well BMW8

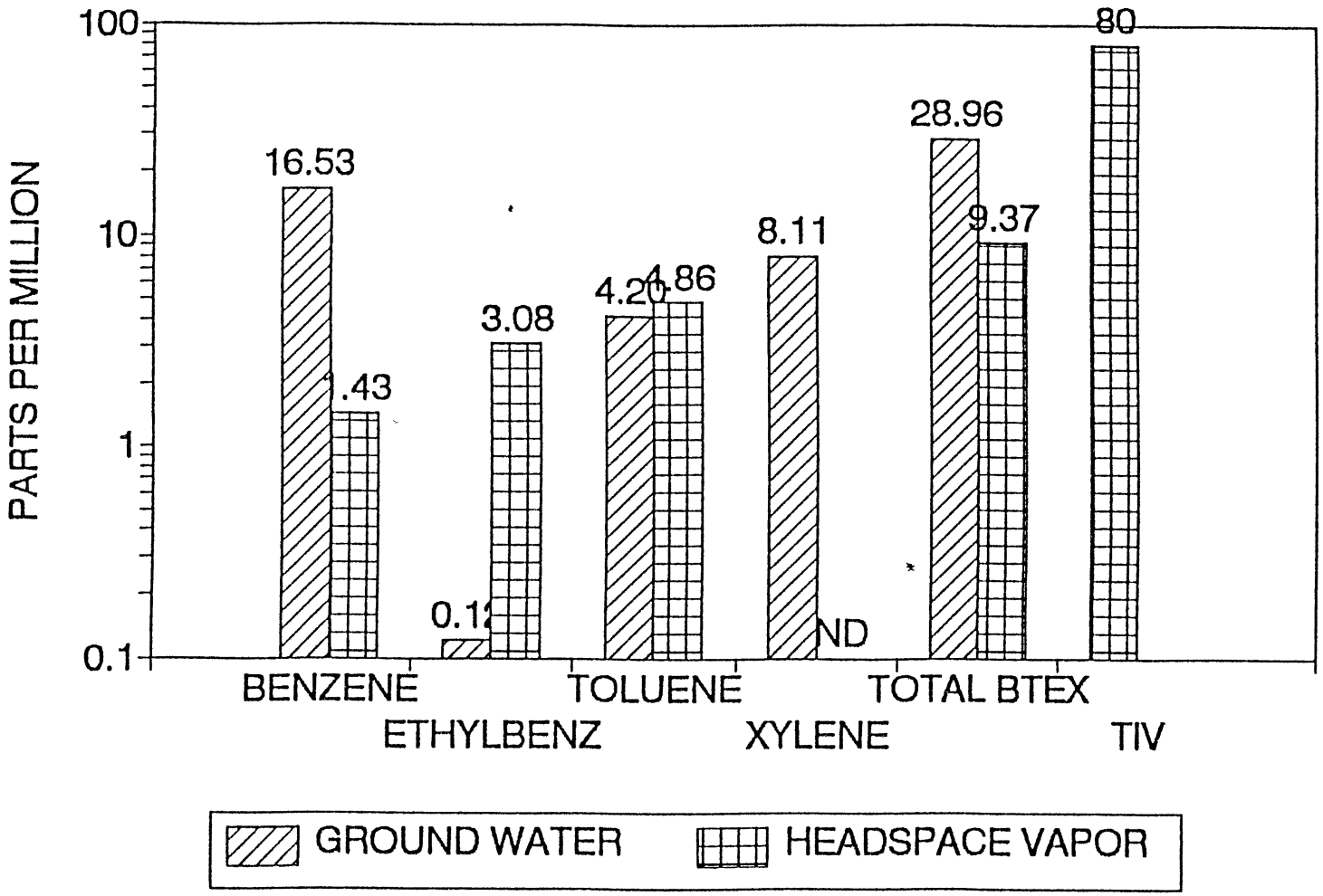


Figure 66. Bar graph comparing VOC concentrations in ground water with well headspace vapor, well BMW12

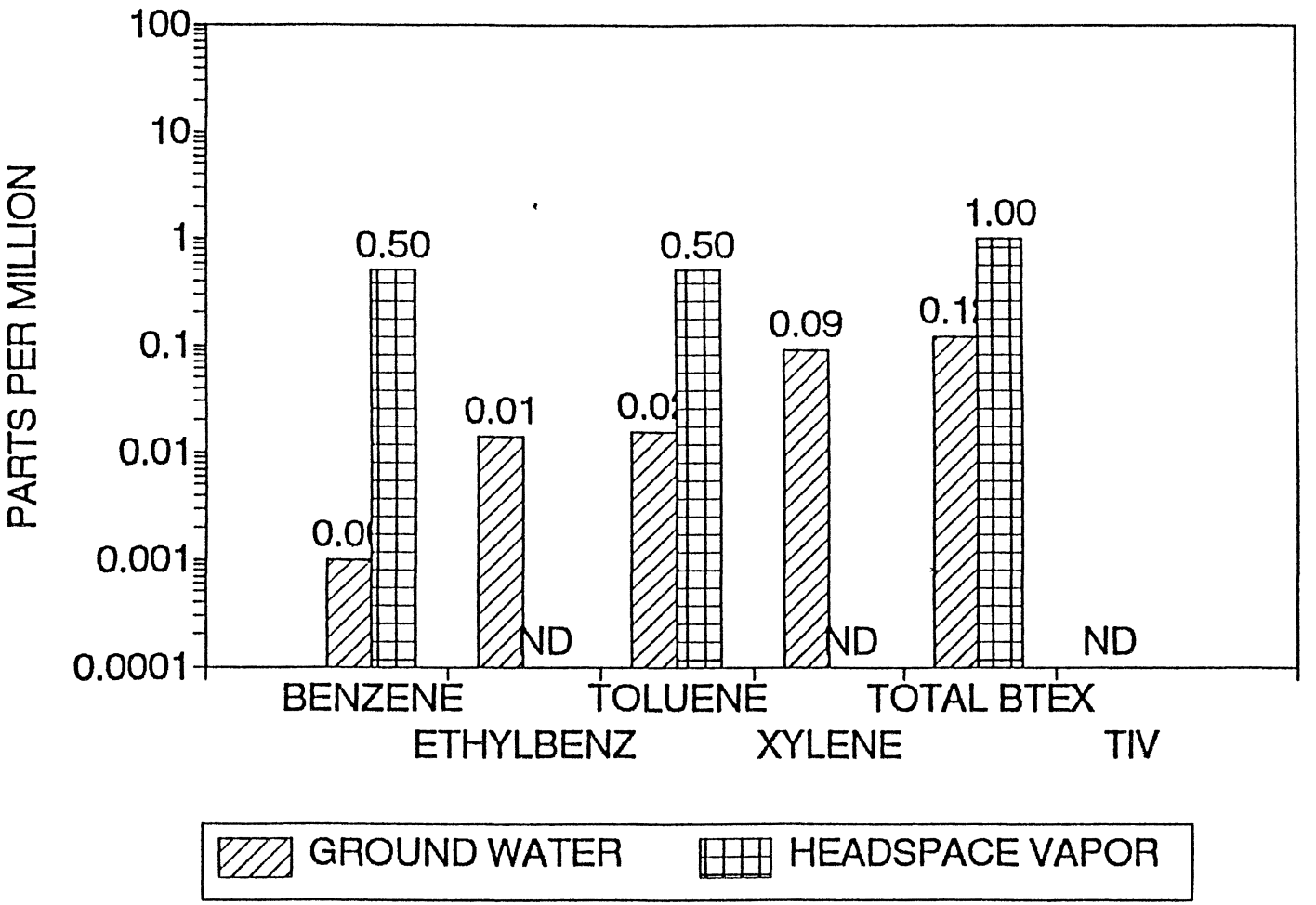


Figure 67. Bar graph comparing VOC concentrations in ground water with well headspace vapor, well BMW14

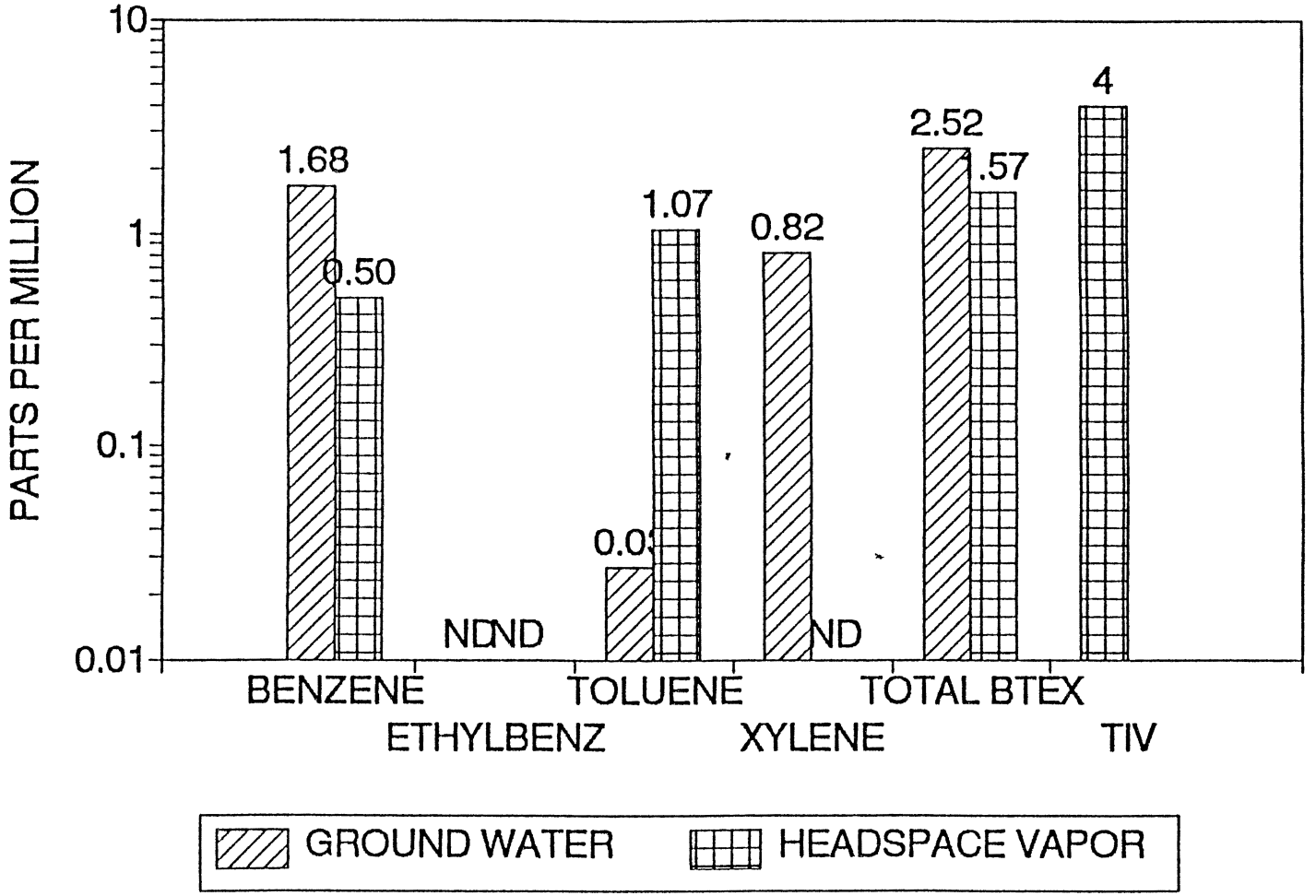


Figure 68. Bar graph comparing VOC concentrations in ground water with well headspace vapor, well BMW16

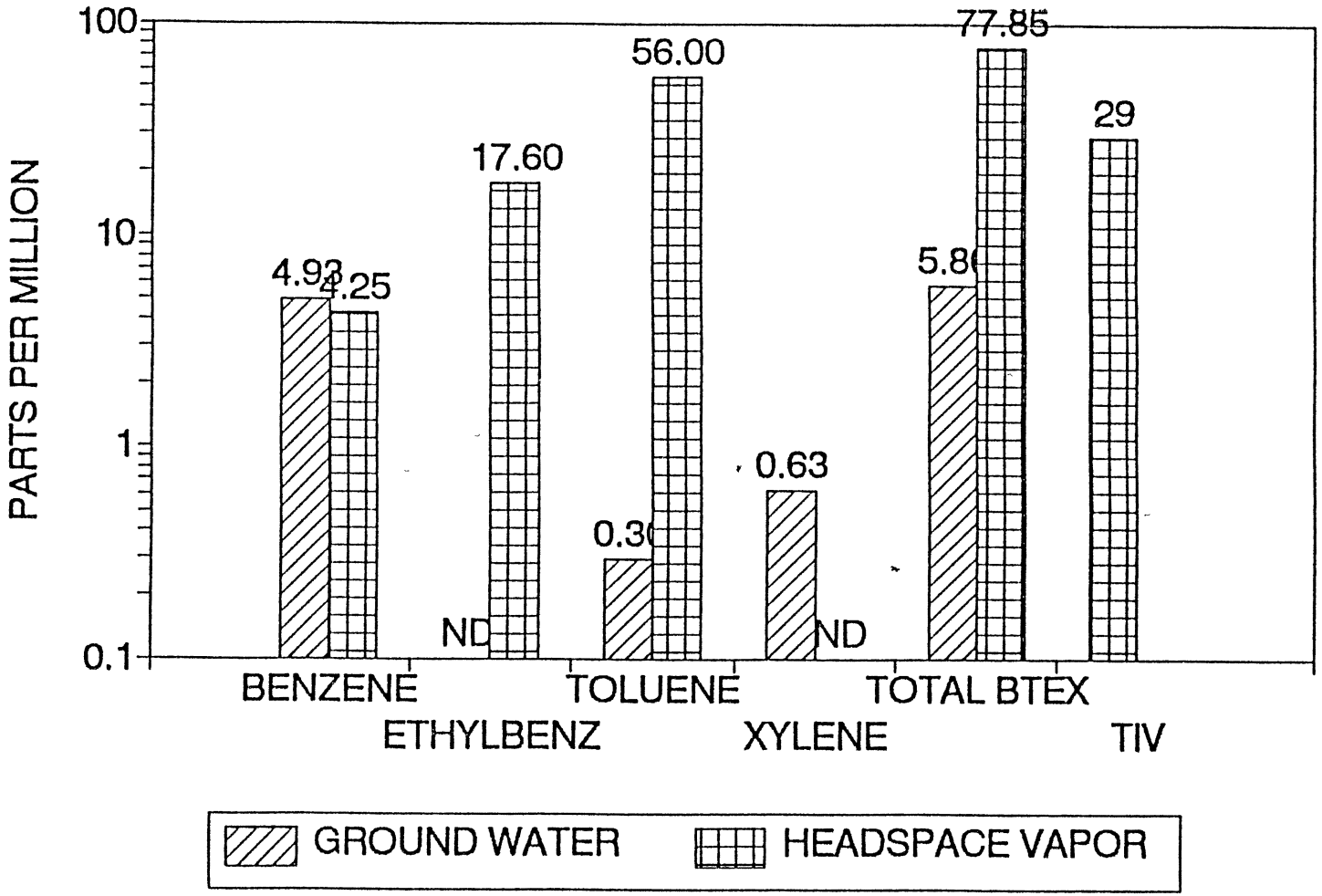


Figure 69. Bar graph comparing VOC concentrations in ground water with well headspace vapor, well BMW17

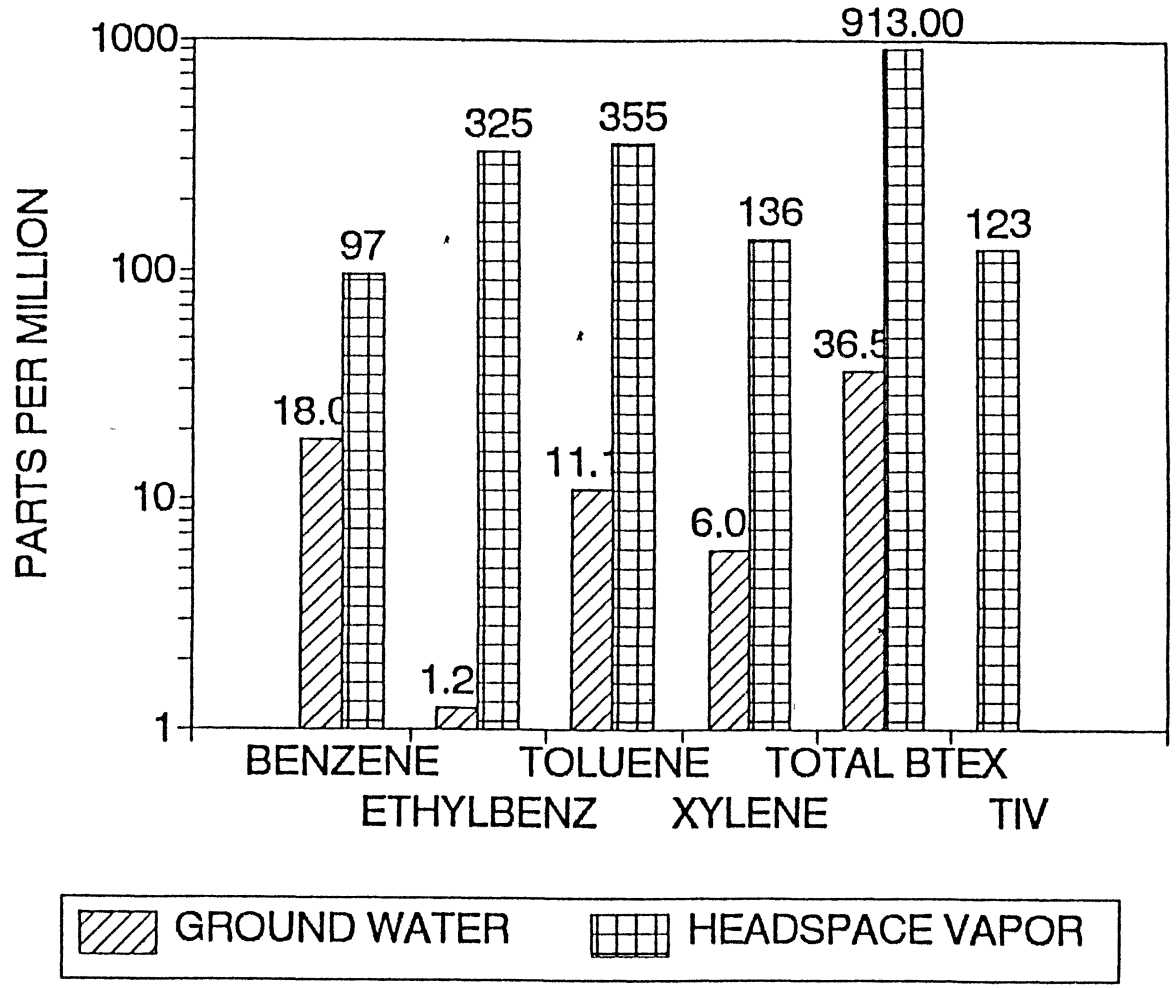


Figure 70. Bar graph comparing VOC concentrations in ground water with well headspace vapor, well BMW22

remove xylene from the vapor phase. The properties of ethylbenzene and the xylenes are very similar, yet ethylbenzene is detected in some of the vapor samples. Xylene was detected in the calibration standard gas mixture with excellent accuracy during the quality-control runs while the headspace vapor samples were being analyzed, so GC error is unlikely as the cause for the missing xylenes.

Toluene concentrations in headspace vapor were consistently higher than in ground water, as was ethylbenzene, while benzene was usually much lower. This may be due to the differences in vapor pressures; benzene has a much higher vapor pressure than the other BTEX components. A possible explanation may be that in the well casings, the temperature is high enough to allow benzene vapor to diffuse out of the casing vent at a faster rate than it is evolving from solution in the ground water. The other constituents would be left in the headspace vapor, and their concentrations would thus be increased. Sampling of headspace vapors may thus lead to misleading conclusions if such factors are not accounted for.

The PID usually measured higher, but sometimes lower concentrations than the portable GC; however the two concentrations were within the same order of magnitude for each well sampled. Figures 59 and 60, well headspace vapor isoconcentration maps (total BTEX from portable GC and PID TIV), vary widely in concentration values, yet show a similar trend. This trend is also in general agreement

with the isoconcentration maps of soil vapor TIV at 3 feet and ground water total BTEX. The concentration of organic vapors in well headspace is likely to be affected to a much stronger degree by varying environmental conditions than is soil vapor, since the well casing is less well insulated, and there is no soil "buffer zone" above the phreatic surface. However this demonstration shows that sampling of well headspace vapors may also be used (however with questionable reliability) as an indicator of the presence of ground water contamination by volatile organics.

Comparison of Soil Sample Analyses with Soil Vapor Analyses

Soil samples we re collected from cores taken within 4 feet of each of the 4 soil vapor ports and analyzed by standard laboratory methods for BTEX constituents, for comparison to analyses of soil vapor collected from the same points at the same time. The soils were analyzed using a sonication extraction procedure with water as a solvent. This procedure uses ultrasonic vibration to mix the soil with the solvent, and a carrier gas is then bubbled through the soil/water mixture for extraction of a sample for injection into the gas chromatograph. The extraction procedure is expected to produce somewhat different results than those obtained by sampling soil vapor, because it will extract compounds adsorbed to soils, which may not be detected in soil vapor. A correlative

relationship between total BTEX in vapor and soil is expected, however, with possible variations caused by differing adsorption characteristics of different soil types.

Figures 71 through 73 are bar graphs which compare concentrations of each BTEX component, total BTEX and PID TIV for soil extractions and soil vapor samples at each sample site. Soil vapor samples used for this comparison were collected from the core holes at the same time as the soil samples, as described in Chapter 4, and contained in Tedlar bags for later analysis off-site by portable GC. Nearly all the BTEX component concentrations in vapor as measured by portable GC exceeded those in the soil samples, with the exception of those which were close to or below the detection limit of the portable GC. (These were all BTEX components in SVP3 and benzene in SVP4). Also In these vapor samples, as in the well headspace vapor samples, no xylene was detected, although every soil sample contained xylene. Again the reason is unclear, but may be explained as discussed earlier in this chapter.

The soil vapor sample from SVP1 produced BTEX concentrations much higher than did the soil sample, as did SVP2; the vapor from SVP4 produced BTEX concentrations much more similar to the soil analysis. These differences in correlation of BTEX concentrations between soil and soil vapor may be due to soil type: SVP1 lies in a clayey silt to silty clay; SVP2 lies in a sandy silt; and SVP4 lies in

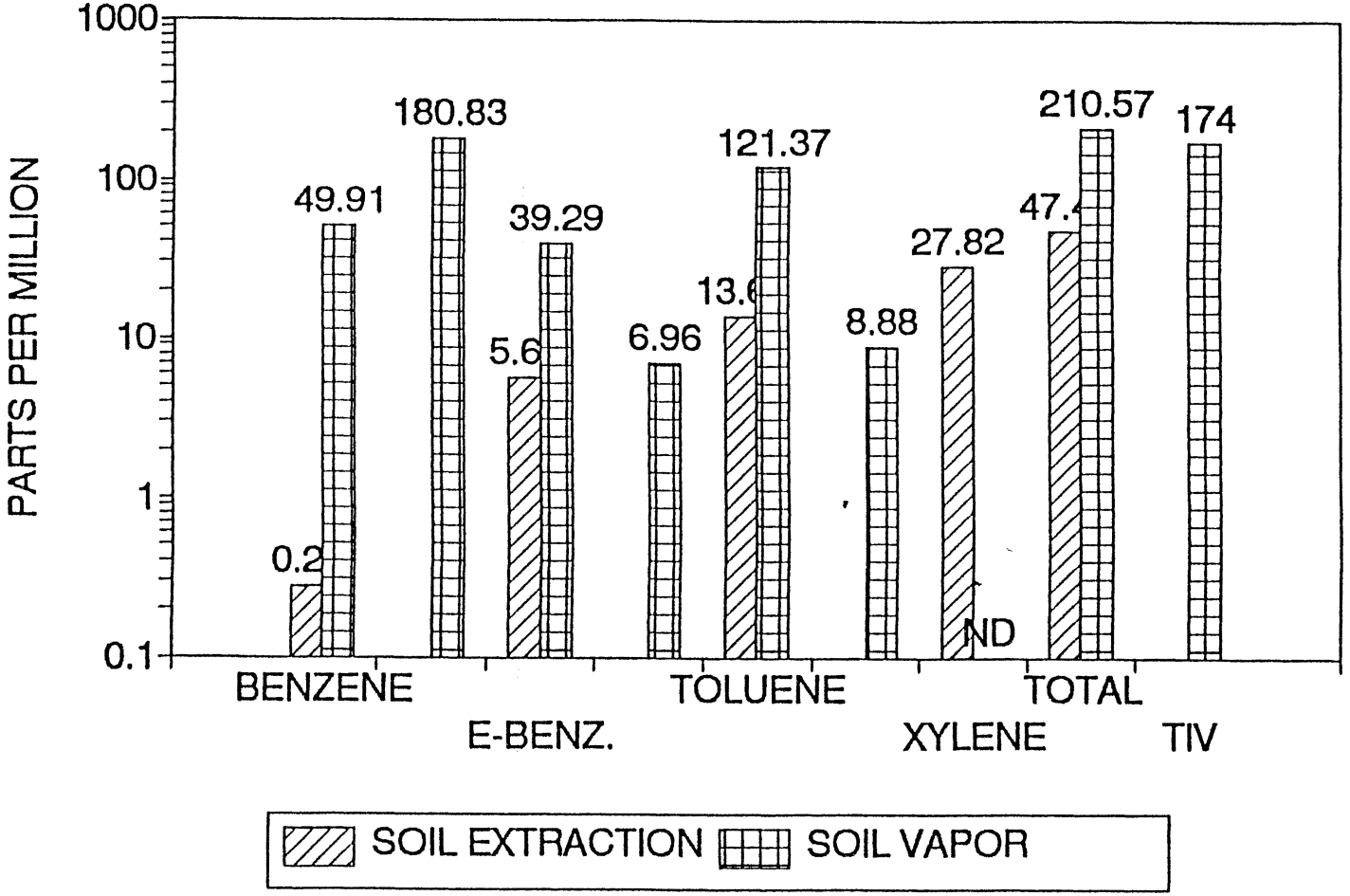


Figure 71. Bar graph comparing BTEX concentration from soil extraction analysis and soil vapor in SVP1

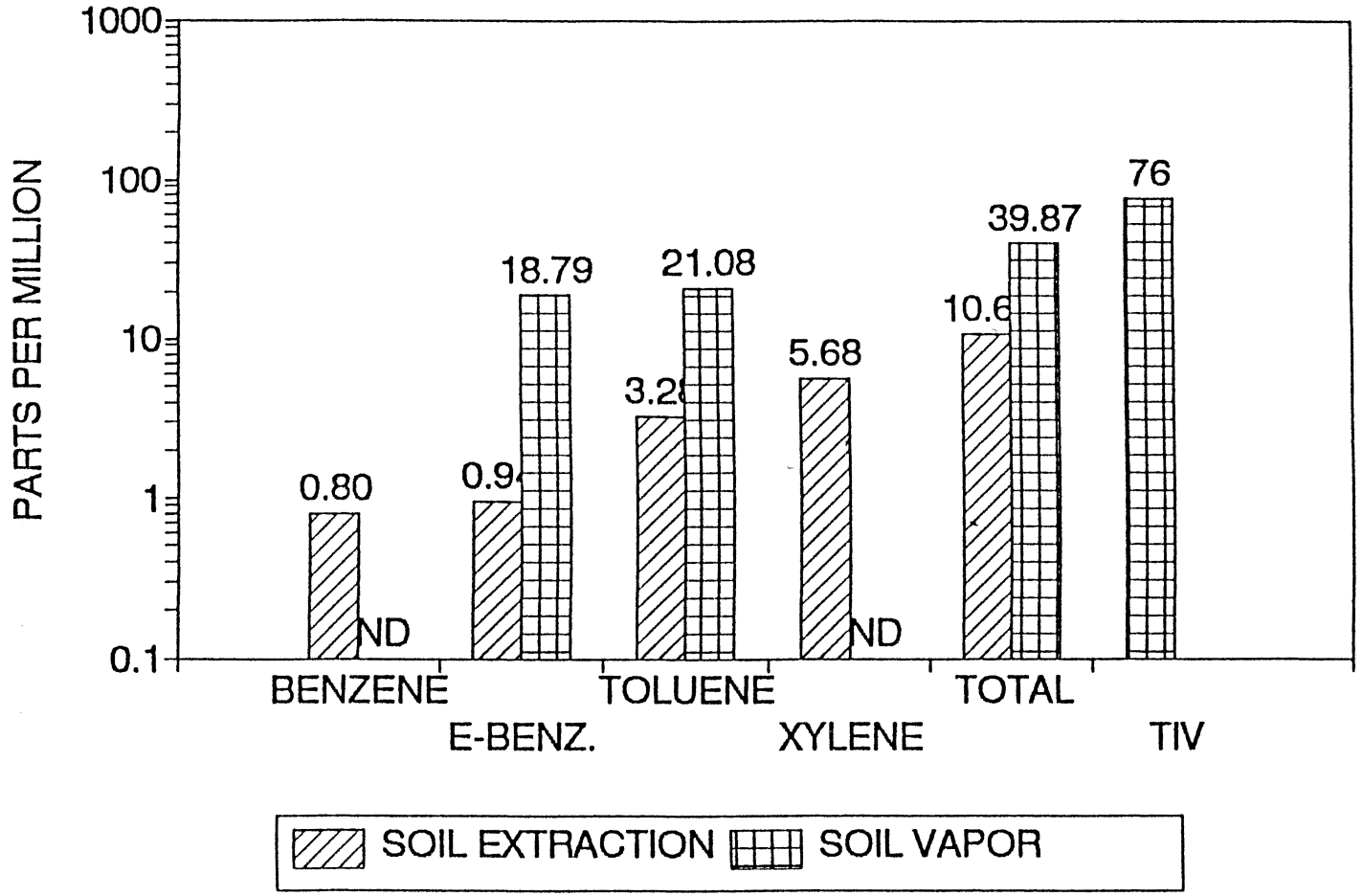


Figure 72. Bar graph comparing BTEX concentration from soil extraction analysis and soil vapor in SVP2

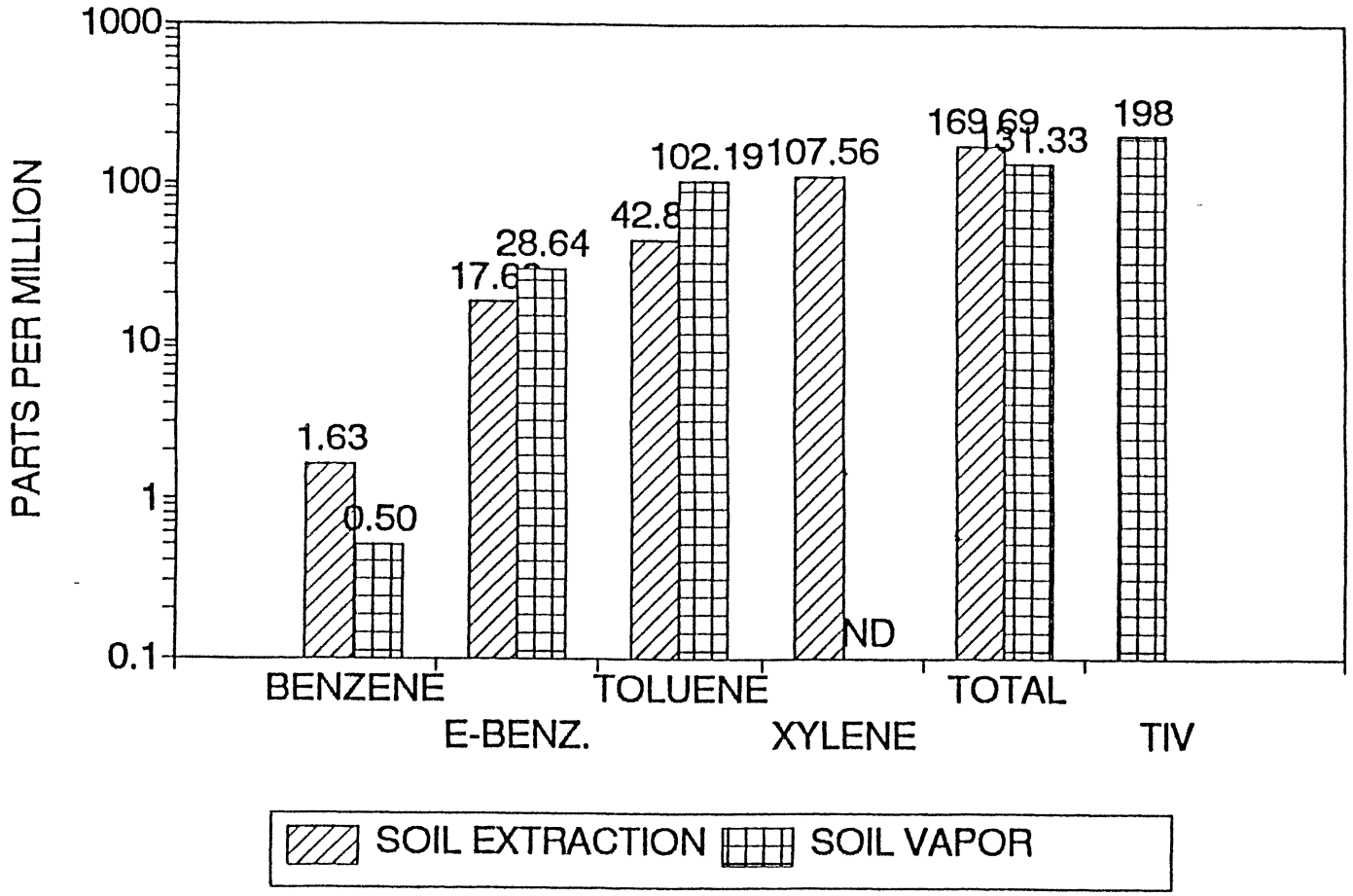


Figure 73. Bar graph comparing BTEX concentration from soil extraction analysis and soil vapor in SVP4

a slightly silty clay. Clay, due to its much higher surface area to volume ratio and more prominent electrical properties, would tend to adsorb more of these volatiles, and allow less free passage of the vapor phase to reach the vapor sampling point, also as a function of its lower effective porosity. Silt would be intermediate in this relationship, and sand would adsorb the least. The clay surrounding SVP4 has apparently adsorbed a larger proportion of volatiles as compared to the those in the vapor phase, as the quotient between the concentration in soil and in vapor is smaller than in either SVP1 or SVP2. This postulation is complicated by the fact that free product and/or volatile-laden ground water has come into contact with the soil at all these sample points during the abnormally high water table conditions of Spring, 1990. Thus the relative amount of apparent soil adsorption is probably amplified here.

Sample point SVP2 is located next to well BMW22; since BMW22 contains no floating hydrocarbon, the water from this well was sampled for BTEX analysis. (The wells near SVP1 and SVP4 both contain floating product, so the water in these wells were not sampled). Figure 74 compares the analyses from ground water, soil and soil vapor at SVP2. As illustrated, benzene was lower in the soil analysis and absent in soil vapor; ethylbenzene was slightly lower in soil but much higher in soil vapor; toluene was lower in soil but higher in soil vapor; and xylene concentrations

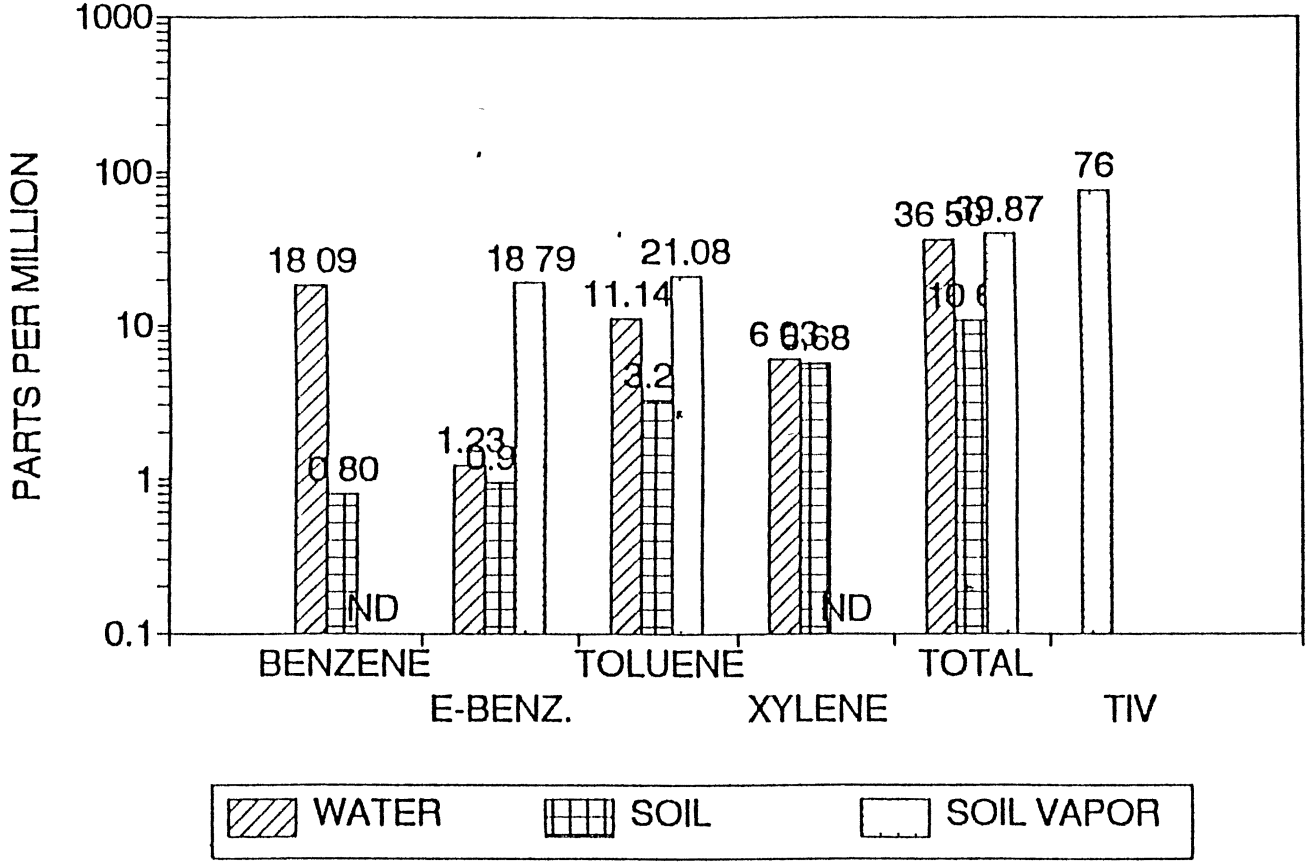


Figure 74. Bar graph comparing BTEX concentration in soil, soil vapor and ground water near well BMW22

were essentially equal in soil and water but absent in soil vapor. The generally lower concentrations in soil at this sample site may be due to the more sandy lithology with its lower adsorption characteristics.

The lower concentrations of benzene in soil vapor may be due to biodegradation of the vapor phase; the soil temperature in SVP1 was consistently higher than in the other two sample sites, possibly indicating a higher rate of biotic activity there. This would be consistent with the coarser grain size at SVP2, which allows better soil gas exchange; oxygen has been shown to be the limiting factor in the rate of biodegradation rate in soils (Baehr and Corapcioglu, 1984). The oxygen level in soil vapor from SVP2 was also the lowest of the three samples measured, at 10%, compared to 13% in SVP1 and 17% in SVP4; this is another indication of high biotic activity. The higher concentrations of ethylbenzene and toluene in soil vapor may be due to concentration by means of differential biodegradation; as the benzene is degraded first, the relative concentrations of the other constituents increase. The lack of xylenes in soil vapor may be explained as discussed earlier in this paper. These samples show that in general BTEX concentrations in soil vapor do not correspond well with that in ground water or soils at this site. In addition, there are apparently many factors which must be taken into account in order to interpret the

concentration of volatiles in soil vapor for estimation of the concentration of volatiles in soil or ground water.

Correlation of Soil Organic Vapor Concentrations with Changing Environmental Variables: Anticipated versus Observed Effects and Linear Regression Analyses

As previously discussed in Chapter II, Literature Review, the occurrence and movement of organics in soil vapor is affected by a large number of environmental factors as well as by the actual measurement methods. The environmental factors measured in this study are: soil moisture, soil temperature, ambient air temperature, barometric pressure, and relative humidity. The relative effects of these variables on soil organic vapor concentration in the field may be estimated based on the physico-chemical principles discussed in Chapter II. In this section, the anticipated effects of each measured variable are briefly described, followed by a description the effects observed in the field.

The sequential soil organic vapor concentrations measured from the soil vapor ports and nearby core holes were compared by statistical analysis to all recorded weather variables and soil moisture percentages. These comparisons are made to determine whether a relationship may be established to determine what relative effect each of the variables has on soil organic vapor concentrations

measured in the field. The variables were analyzed separately for each sample point by visual inspection of plots of the independent variables versus the TIV concentration values measured during the study and by linear regression (method of least squares), for both the entire data set and the closely-spaced (diurnal) data. The method of least squares, or linear regression, describes a line, Y = Ax + B, by using the following equations, for n number of observations of an independent variable (X) and a dependant variable (Y), where:

A = nsumXY - sumXsumY / n(sumX2) -(sumX)2, and

B = sumY(sumX2) - sumXsumXY / nsum(X2) - (sumX2).

The dependant variable coefficient (A), the regression constant (B) and the R2 value are computed by the computer program SYSTAT for each regression (Wilkinson, 1988). The R2 value indicates the "goodness of fit" of the correlation, and is between 0 and 1. An R2 value of 1 is a perfect correlation, with no deviation from the straight line relationship between the two variables; the lower the R2 value, the further lie most of the observed values from the line. A coefficient value of 1 is a 45o slope on this line. A positive coefficient indicates that the dependant variable (in this case organic vapor concentration) increases with the independent variable; a negative coefficient indicates that as the independent variable increases, the dependant variable decreases. Table VII

TABLE VII

LINEAR REGRESSION CALCULATION RESULTS

SOIL VAPOR PORT 1: LONG-TERM DATA

	INDEPENDANT VARIABLE						
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED	DEPTH TO FLUID	SOIL TEMP.	% SOIL MOIST.
R2	0.571	0.09	0.246	1.6E-05	0.034	0.715	0.228
COEFF.	3.606	-2.993	1.626	0.0024	-36.742	5.859	-50.26

SOIL VAPOR PORT 1: DIURNAL DATA

	INDEPENDANT VARIABLE			
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED
R2	0.522	0.715	0.366	0.008
COEFF.	0.553	-1.23	-0.211	0.103

SAMPLE POINT 1, OPEN CORE HOLE DATA

	INDEPENDENT VARIABLE						
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED	DEPTH TO FLUID	SOIL TEMP.	% SOIL MOIST.
R2	0.574	0.078	0.081	0.151	0.0002	0.626	0.0001
COEFF.	2.719	-2.226	1.537	1.847	-2.108	5.03	-0.663

SOIL VAPOR PORT 2: LONG-TERM DATA

	INDEPENDENT VARIABLE						
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED	DEPTH TO FLUID	SOIL TEMP.	% SOIL MOIST.
R2	0.662	0.289	0.303	0.093	0.152	0.913	0.004
COEFF.	4.049	-6.626	1.747	-1.996	-147.78	6.527	4.343

SOIL VAPOR PORT 2: DIURNAL DATA

	INDEPENDENT VARIABLE			
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED
R2	0.06	0.116	0.059	0.58
COEFF.	0.242	-0.639	-0.109	1.139

TABLE VII (Continued)

SAMPLE POINT 2, OPEN CORE HOLE DATA

	INDEPENDENT VARIABLE						
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED	DEPTH TO FLUID	SOIL TEMP.	% SOIL MOIST.
R2	0.633	0.054	0.178	0.133	0.056	0.749	0.063
COEFF.	4.672	-2.326	3.467	2.69	108.427	8.48	23.159

SOIL VAPOR PORT 4: LONG-TERM DATA

	INDEPENDENT VARIABLE						
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED	DEPTH TO FLUID	SOIL TEMP.	% SOIL MOIST.
R2	0.52	0.089	0.246	0.138	0.679	0.914	0.004
COEFF.	3.589	-2.889	1.626	-2.357	-111.74	6.902	2.186

SOIL VAPOR PORT 4: DIURNAL DATA

	INDEPENDENT VARIABLE			
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED
R2	0.007	0.037	0.002	0.009
COEFF.	-0.052	0.233	-0.013	-0.091

SAMPLE POINT 4, OPEN CORE HOLE DATA

	INDEPENDENT VARIABLE						
	TEMP	BAR. PRESS.	REL. HUM.	WIND SPEED	DEPTH TO FLUID	SOIL TEMP.	% SOIL MOIST.
R2	0.154	0.234	0.081	0.266	0.004	0.372	0.051
COEFF.	1.517	-3.622	1.537	2.235	-7.414	3.804	-7.532

lists R2 values and coefficients (slopes) for all linear regression calculations.

Multiple linear regressions were then calculated for each sample point, again both for the long-term data and the diurnal data in attempt to isolate the effects of each independent variable and to identify collinear or codependant effects. (The computer program printout for each calculation is included as Appendix E).

Figure 75 illustrates the changes observed in weather variables at each sample event date; this graph shows that temperature and relative humidity have tended to increase throughout the course of the study, while barometric pressure has decreased. Wind speed also shows a somewhat parallel relationship with temperature. Figures 76 and 77 illustrate changes in soil vapor concentrations at each sample point, for each sample event date. Figure 78 lists all data collected for correlation of weather variables with soil vapor concentration. As is evident in this data, sample point 3 was deleted from the study after the soil organic vapor concentration fell to zero, at which point the data from this point was no longer of use.

Ambient Air Temperature Effects

An increase in air temperature will increase the temperature gradient from the liquid hydrocarbon source to the atmosphere: this increase in temperature gradient is expected to create an overall decrease in the soil organic

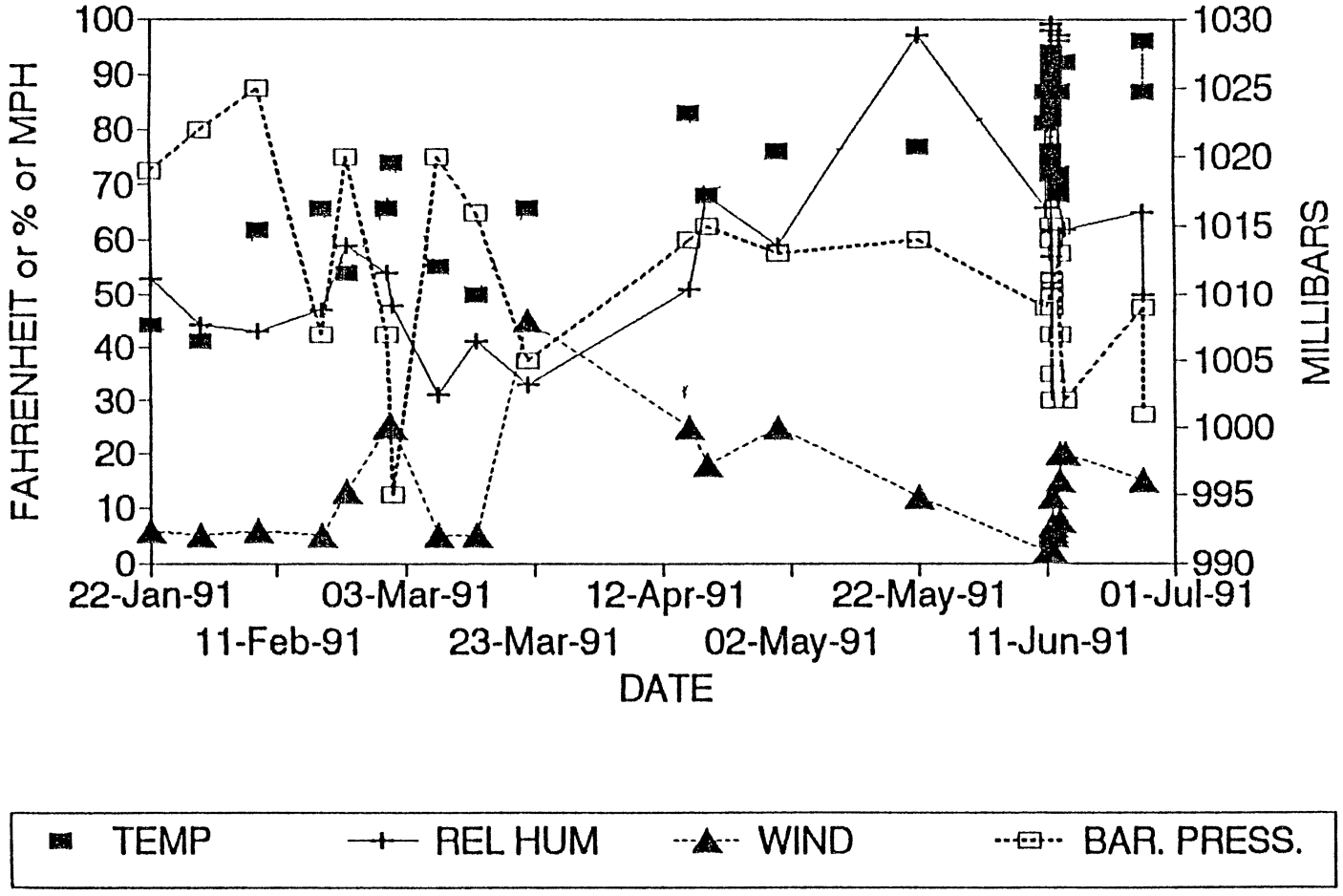


Figure 75. Weather variables measured during sample events

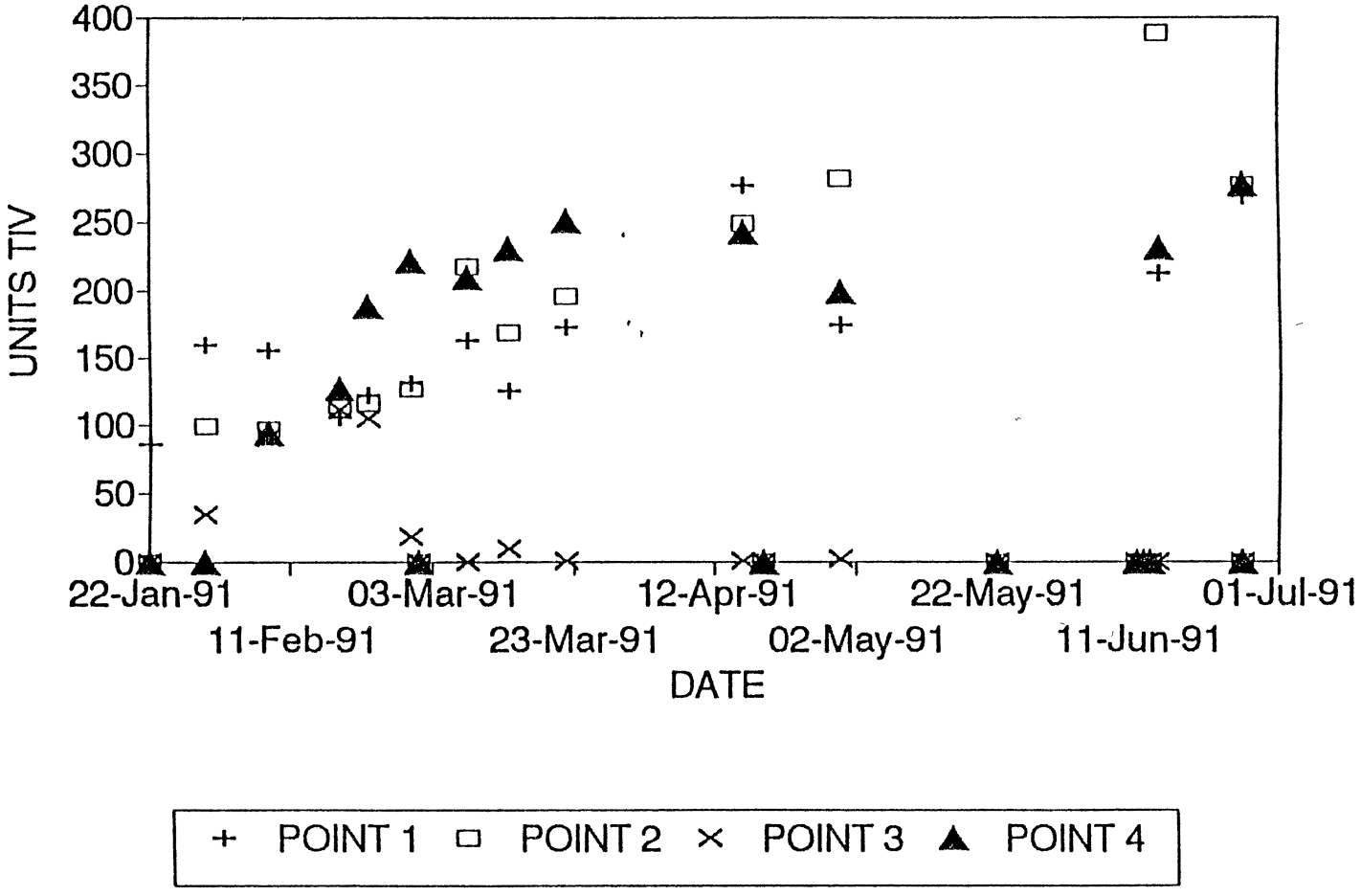


Figure 76. TIV measurements in core holes

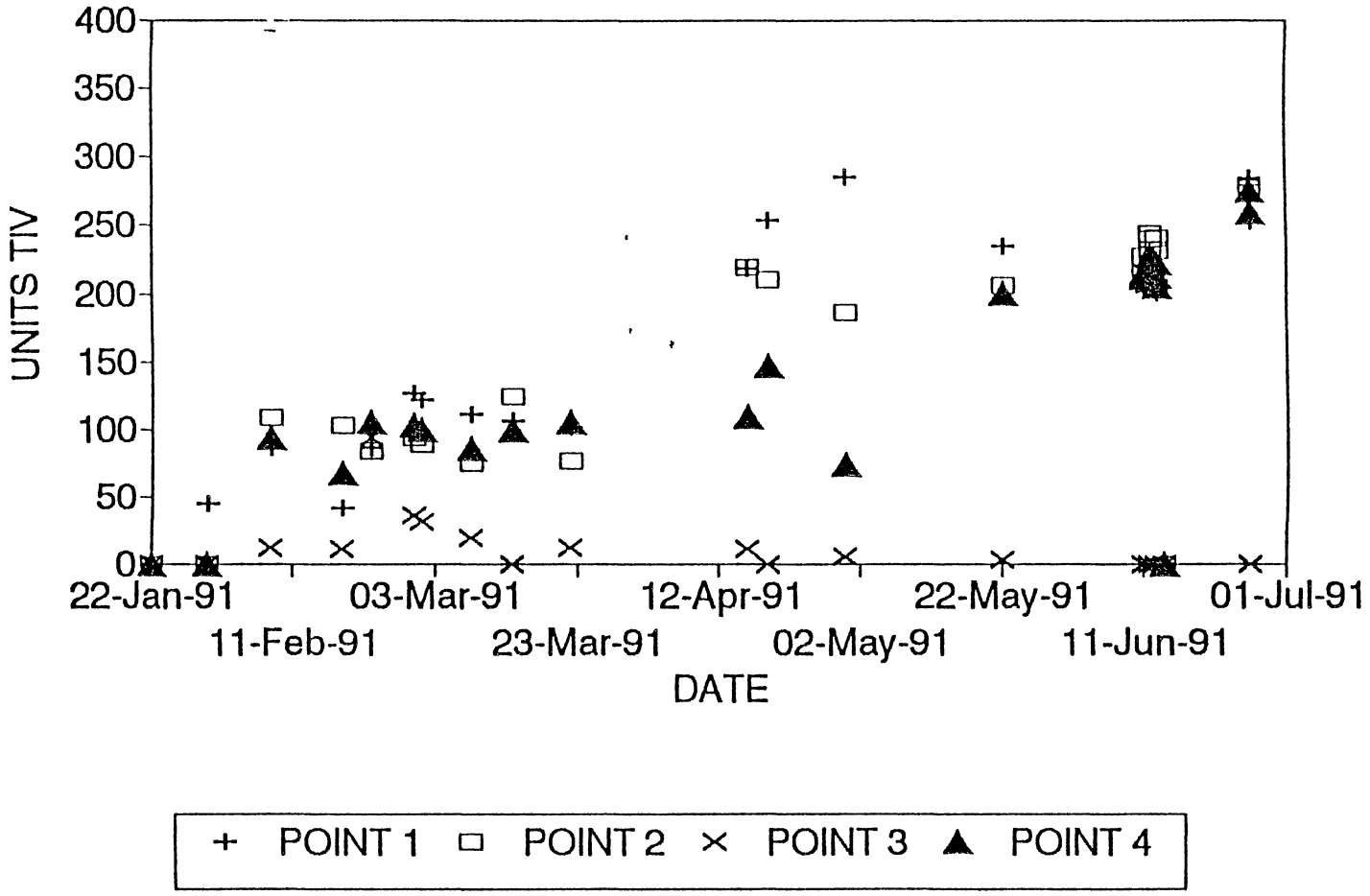


Figure 77. TIV measurements in soil vapor ports

DATE	n	TIME	HRS INTO DIURNAL STUDY	AIR TEMP. (F)	% REL. HUM (AIR)	BAR PRESS (mBAR)	WIND SPEED	DEPTH TO FLUID BELOW SAMPLING POINT				SOIL TEMPERATURE (* = estimated)				% SOIL MOISTURE (WEIGHT)				TOTAL IONIZABLE VAPOR (TIV) (core hole)				TIV in PORT			
								SAMPLE POINT				SAMPLE POINT				SAMPLE POINT				SAMPLE POINT							
								1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
22-Jan-91	1	12		44	53	1019		6 1 42	1 03	3 84	1 43	* 52 0	52 5 .		51 7					86 .	.		.	.	.	
30-Jan-91	2	15		41	44	1022		5 1 47	1 09	3 88	1 48	* 52 3	52 8 .		52 0	15.1	14 1	13 9		160	99	35 .		45 .	.	.	
08-Feb-91	3	18		62	43	1025		6 1 52	1.16	3 93	1 53	* 53 0	53 5 .		52 7	14 1	15 1	16 9	19 1	155	97	91	94	87	109	12	94
18-Feb-91	4	18		66	47	1007		5 1 58	1 23	3.98	1.59	* 53 8	54 3 .		53 5	13 5	14 7	15 1	13 5	105	114	111	127	41	103	11	68
22-Feb-91	5	10		54	59	1020		13 1 60	1 26	4 00	1 61	* 54 1	54 6		53 8	12 5	13 6	16 3	14 2	122	117	104	188	87	85	95	105
28-Feb-91	6	17		66	54	1007		25 1 74	1 30	4.07	1 68	* 54 8	55 3 .		54 5	13 3	11 8	16 8	16 9	131	126	18	222	127	94	36	103
01-Mar-91	7	13		74	48	995		25 1 69	1 31	4 08	1 70	* 55 1	55 6		54 8		.							122	89	31	100
08-Mar-91	8	11		55	31	1020		5 1 76	1 36	4.15	1 78	* 56 1	56 6 .		55.8	13 1	13 1	15 5	14 5	163	217	0	209	111	76	19	86
14-Mar-91	9	14		50	41	1016		5 1 87	1 40	4 22	1 85	57 6	57 0	55 0	56 2	14 3	14 4	16 6	14 4	125	168	9	230	107	124 .		100
22-Mar-91	10	15		66	33	1005		45 1 94	1 45	4 31	1 95	57 4	57 9	56 1	56 5	13 4	15 1	16 2	16 3	173	195	0 5	251	101	77	12	106
16-Apr-91	11	12		83	51	1014		25 2 18	1 62	4 58	2 26	64 4	65 1	62 4	63 1	14 2	14 2	16 9	14 6	277	249	0 5	243	218	219	10	110
19-Apr-91	12	16		68	68	1015		18 2 21	1 64	4 61	2 30	* 64 7	65 2 .		62 7			.			.			254	210	0	147
30-Apr-91	13	12		76	59	1013		25 2 31	1 72	4 73	2 43	65 7	65 5	63 5	63 7	12 6	14 7	15 8	16 8	174	282	1 5	198	286	186	4 8	75
22-May-91	14	17		77	97	1014		12 1 81	1 29	3 89	1 82	* 72 3	73 1 .		70 7							.		235	206	2 5	201
11-Jun-91	15	19 5	0	87	66	1009		2 1 35	1 15	2 82	1 10	* 75 0	75 7 .		73 0						.	.	.	206	214		212
11-Jun-91	16	21 5	2	81	82	1009		2 1 35	1.15	2 82	1 10	* 75 0	75 7		73 0	.							.	213	227 .		215
12-Jun-91	17	0	4 5	76	91	1011		2 1 32	1 14	2 76	1 06	* 75 0	75 7 .		73 0						.	.		210	224 .		213
12-Jun-91	18	2 5	7	74	98	1014		2 1 32	1 14	2 76	1 06	* 75 0	75 7		73 0							.		208	228 .		215
12-Jun-91	19	4 25	8 75	72	99	1015		2 1 32	1 14	2 76	1 06	* 75 0	75 7		73 0			.		.		.	.	206	226 .		214
12-Jun-91	20	11	15 5	83	62	1010		5 1 32	1 14	2 76	1 06	* 75.0	75 7		73 0			.				.		208	223		217
12-Jun-91	21	12 25	16 75	88	57	1009		7 1 32	1.14	2 76	1 06	* 75 0	75 7 .		73 0	.							.	207	232		227
12-Jun-91	22	15	19 5	93	52	1004		12 1 32	1 14	2 76	1 06	* 75 0	75 7		73 0	.								214	244		213
12-Jun-91	23	16 25	20 75	94	51	1002		12 1 32	1.14	2 76	1 06	* 75 0	75 7		73 0	.						.		218	233		217
12-Jun-91	24	17 75	22 25	92	54	1002		12 1 32	1 14	2 76	1 06	* 75 0	75 7		73 0	.							.	221	239		215
12-Jun-91	25	19 5	24	90	62	1004		7 1 32	1 14	2 76	1 06	* 75 0	75 7		73 0	.								220	229		210
12-Jun-91	26	20.5	25	86	73	1007		6 1 32	1.14	2 76	1 06	* 75 0	75 7 .		73 0	.							.	220	239 .		216
12-Jun-91	27	22.75	27.75	82	84	1010		7 1 32	1 14	2 76	1 06	* 75 0	75 7		73 0	.							.	209	224		209
13-Jun-91	28	6 25	31 5	69	97	1013		8 1 30	1.13	2 71	1 03	* 75 1	75 8		73 1	.								203	232		213
13-Jun-91	29	8 75	34	72	96	1015		15 1 30	1 13	2 71	1 03	* 75 1	75 8 .		73 1	.							.	201	240		223
13-Jun-91	30	12.5	37 75	87	67	1007		20 1 30	1 13	2 71	1 03	* 75 1	75 8 .		73 1	.							.	209	240		205
14-Jun-91	31	13		92	62	1002		20 1 28	1 12	2 66	0 99	75 2	75 9		73 2	13 9	15 2		16 2	213	388 .		232	.	.		.
26-Jun-91	32	10.5		87	65	1009		15 1 00	1 14	2 55	0 92	80 4	81 3 .		78 6	12 6	13 6		15 8	269	277 .		278	285	273		276
26-Jun-91	33	15		96	50	1001		15 1 00	1 14	2 55	0 92	80 4	81 3 .		78 6					.	.	.		253	277 .		259

Figure 78. Data collected during sample events

vapor concentration. A soil temperature increase will "lower the suction and raise the vapor pressure of soil water. Hence the effect of a thermal gradient is to induce flow and distillation from warmer to cooler regions" (Hillel, 1982). Organic vapors would also be expected to flow towards the area of lower temperature. Thus in the winter months, when the earth is warmer than the ambient air, vapor would tend to flow toward the surface, and vice-versa, strictly as a function of temperature gradient. Upward flow of vapors when the air is warmer than the soil is movement against the temperature gradient, and occurs in response to a concentration gradient and/or a matric potential gradient (Marshall and Holmes, 1988).

In a closed system, a temperature increase would necessitate an increase in pressure or a decrease in gas concentration. Of course the atmosphere is not a closed system; however air temperature affects barometric pressure and relative humidity inversely, and air temperature and soil temperature are related. The effects of changing barometric pressure and relative humidity may mask the effects of changing temperature, and the net expected effect of short term change in ambient air temperature is not clear. Certainly long term increasing air temperature, as with seasonal change, should increase soil temperature, hence increasing soil organic vapor concentration.

Figures 79 through 84 are graphs illustrating the relationship of soil organic vapor concentrations to

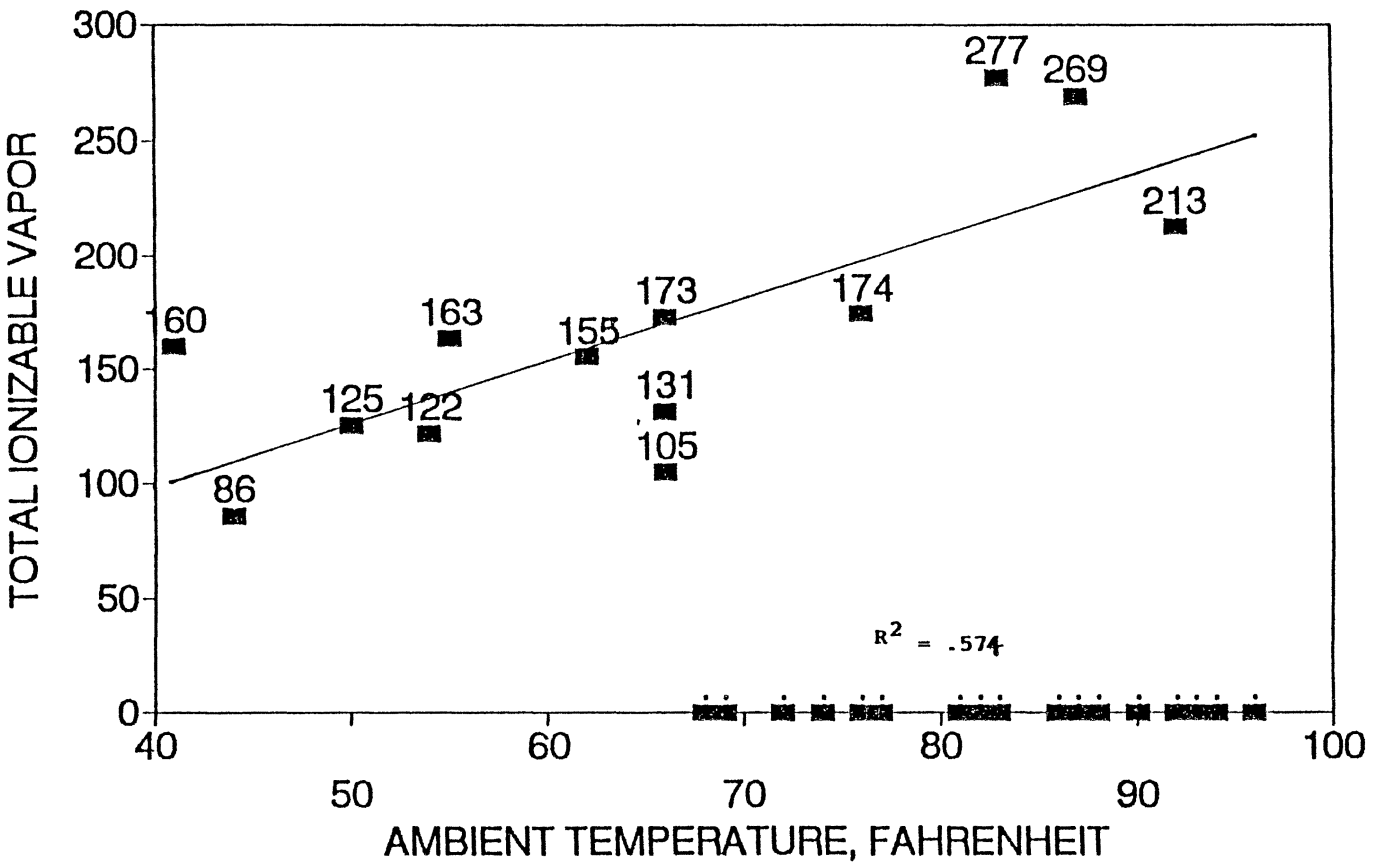


Figure 79. Scatter plot of TIV vs ambient temperature in core holes at sample point 1, with regression line

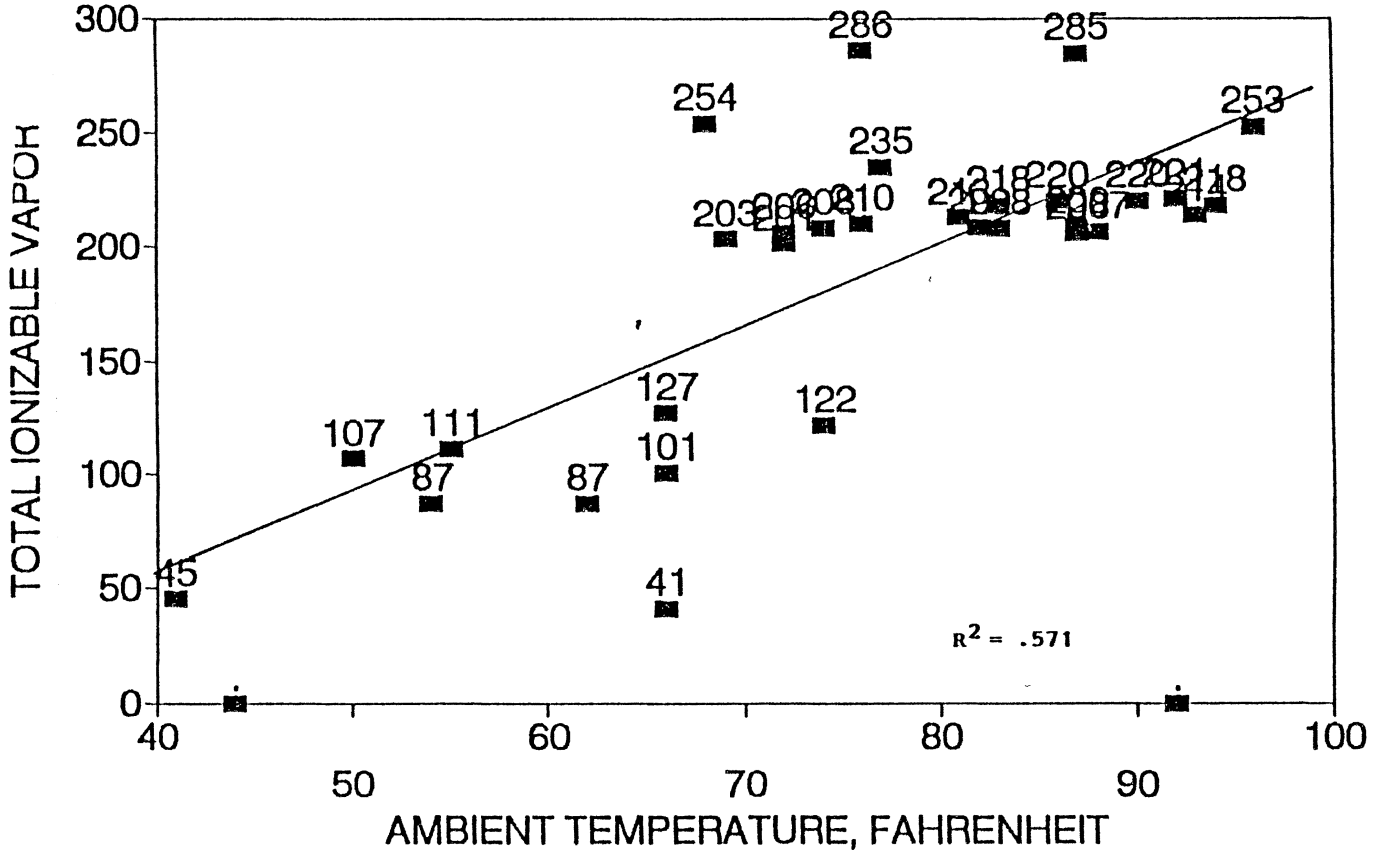


Figure 80. Scatter plot of TIV vs ambient temperature in soil vapor port 1, with regression line

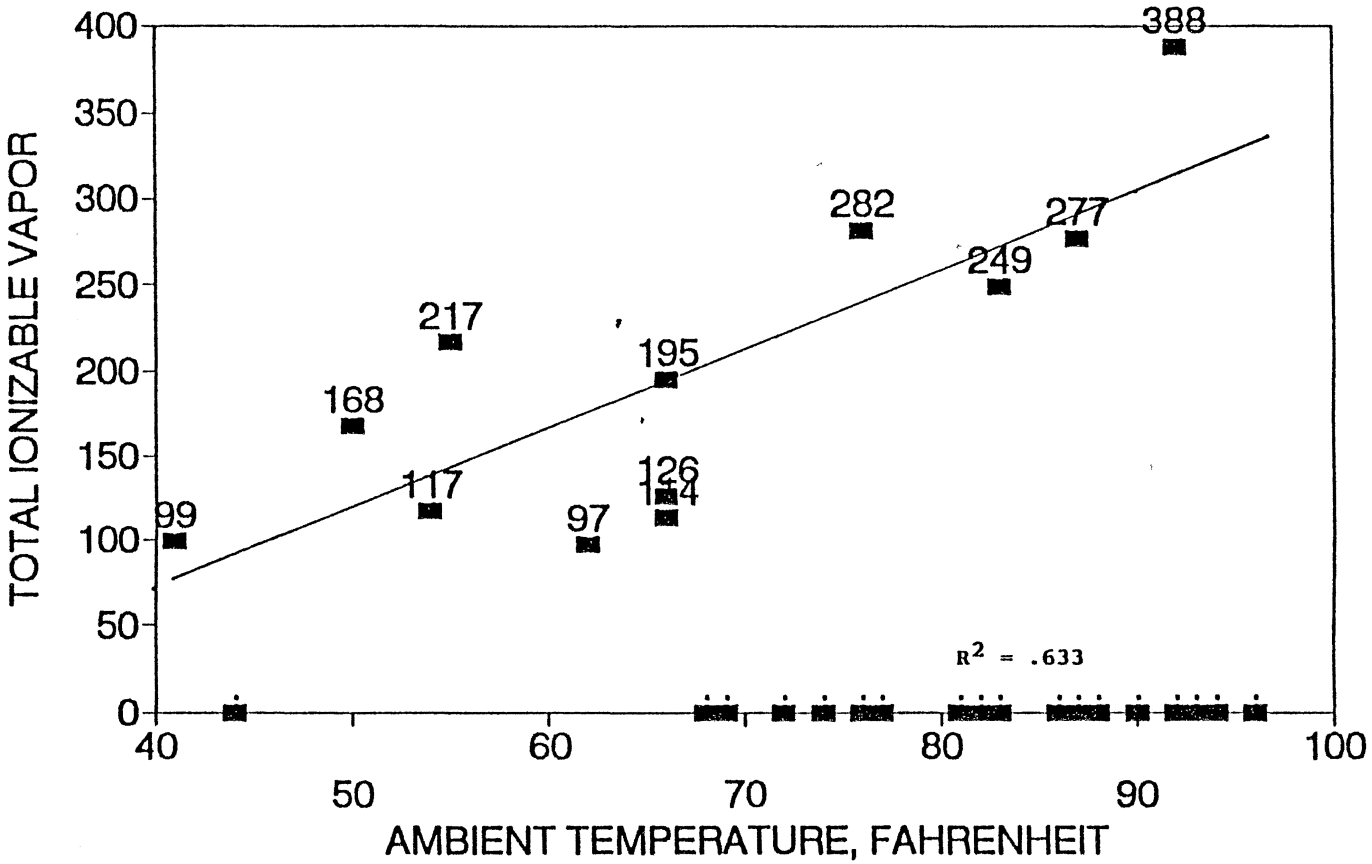


Figure 81. Scatter plot of TIV vs ambient temperature in core holes at sample point 2, with regression line

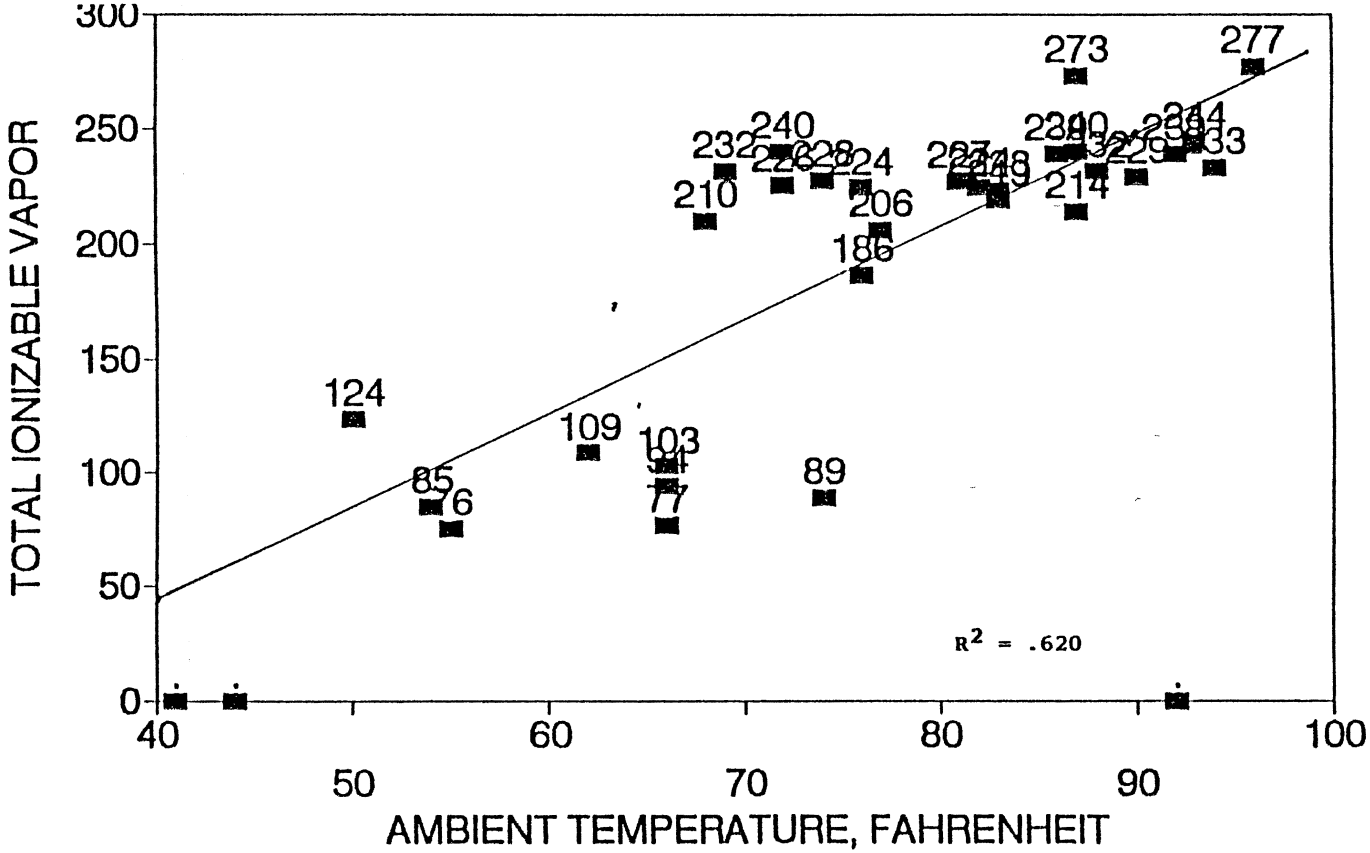


Figure 82. Scatter plot of TIV vs ambient temperature in soil vapor port 2, with regression line

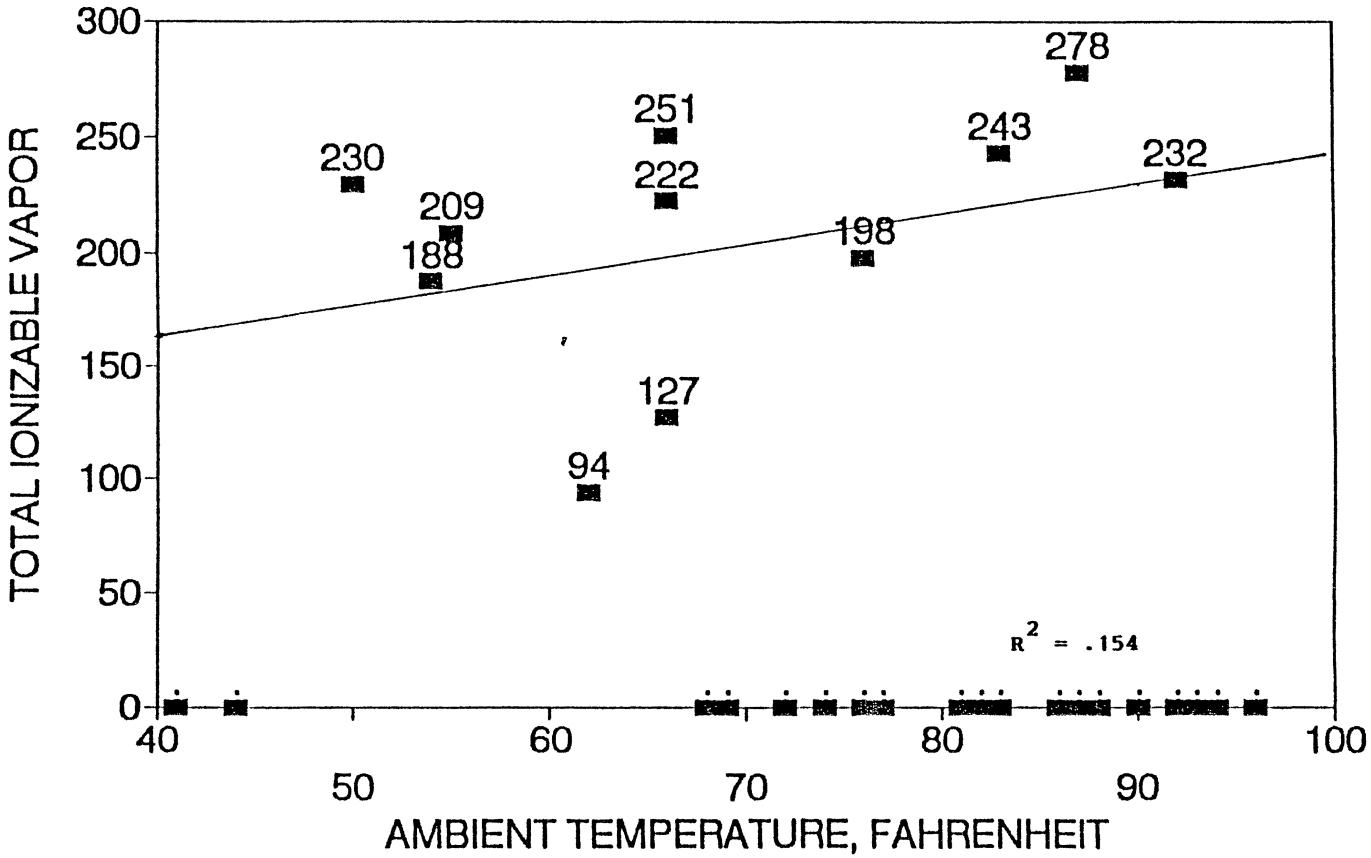


Figure 83. Scatter plot of TIV vs ambient temperature in core holes at sample point 4, with regression line

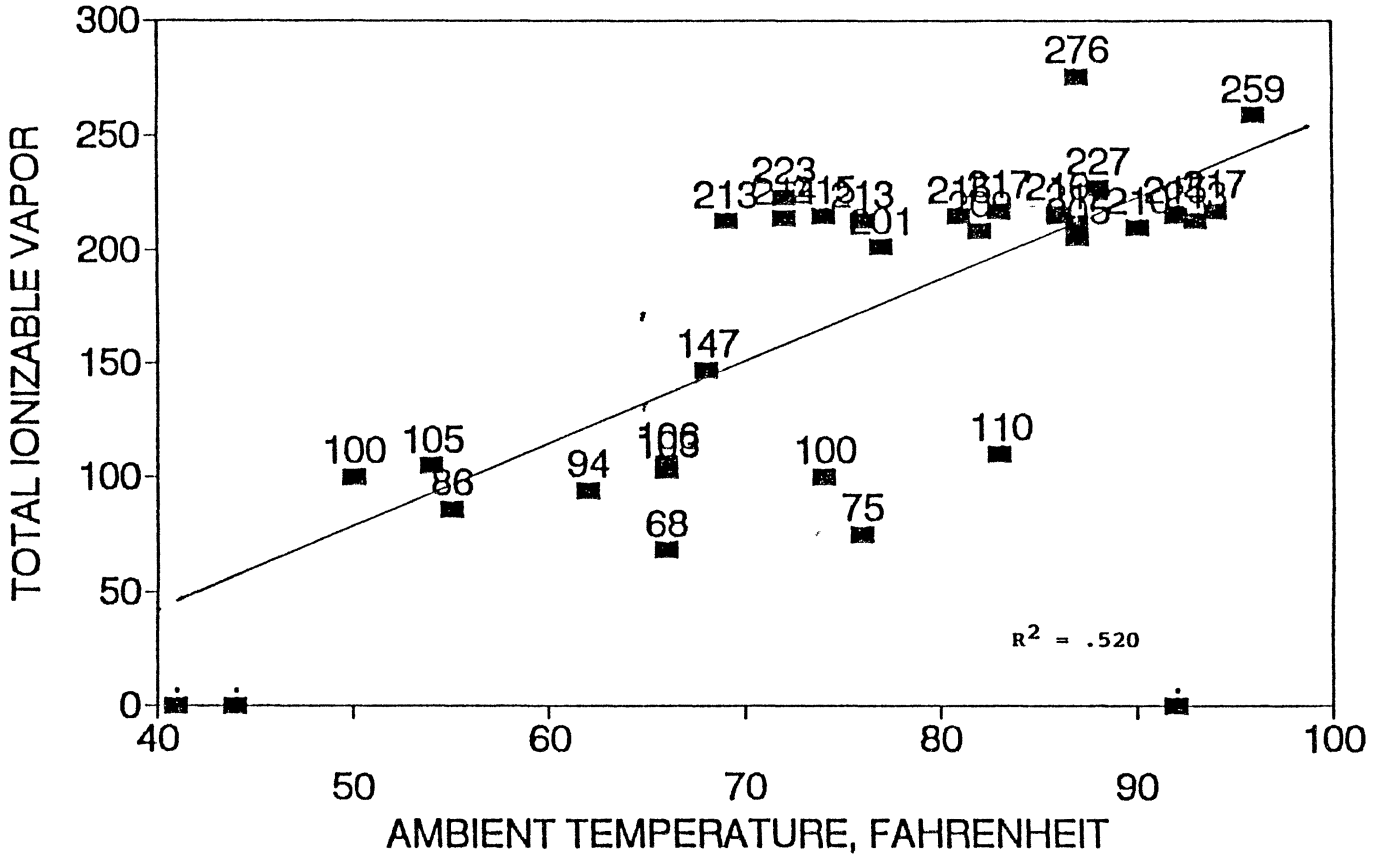


Figure 84. Scatter plot of TIV vs ambient temperature in soil vapor port 4, with regression line

ambient air temperature change for sample points 1, 2 and 4, from the vapor ports and from core holes during the entire course of the study. From visual inspection of these graphs, there appears to be a clearly positive general correlation between ambient temperature and soil vapor concentration. All R2 values are above .5 for this relationship, indicating a somewhat better than random fit on the regression line.

There is an apparent bimodal grouping in the long-term data plots which is especially evident in the data from the soil vapor ports as opposed to that from the core holes. This is in large part due to the tightly-grouped data from diurnal measurements; however even in the core hole data some bimodal grouping is evident. This apparent bimodal grouping is evident to some degree in all the data, and is due mostly to the hiatus in sampling between March 22 and April 16. The relatively large variation in the affecting environmental variables during this period apparently caused a relatively large variation in the measured vapor concentrations.

Ambient air temperature effects are difficult to separate from soil temperature effects over the long term, since soil temperature changes in response to the same factors as the atmosphere, although at the depth of investigation used in this study there is a lag time of about one month, and the changes are less pronounced. In order to remove the influence of soil temperature change,

16 soil vapor samples were collected from the ports at closely spaced intervals over a 3-day period (these measurements are referred to as diurnal measurements). Soil temperature would not be expected to change noticeably during this time span at the measurement depth. As shown by Figures 81 through 83, the correlation between soil vapor concentration and ambient temperature during the short term is poor for sample points 2 and 4. Sample point 1, however, showed a moderately well-defined positive visual correlation between ambient air temperature and soil total ionizable vapor concentration over the short term. Diurnal temperature change is accompanied by an opposite change in barometric pressure, however, as shown by Figure 88 (PAGE 188), which is a graph of weather variable measurements made during the diurnal study. This codependant relationship may be influencing the possible correlation shown for temperature and organic vapor concentration in SVP1.

Barometric Pressure Effects

Increasing barometric pressure would be expected to result in decreased soil organic vapor concentration as a function of the ideal gas law. Increased barometric pressure would decrease volatilization by increasing solubility, thus decreasing soil organic vapor concentration at a constant distance from the source.

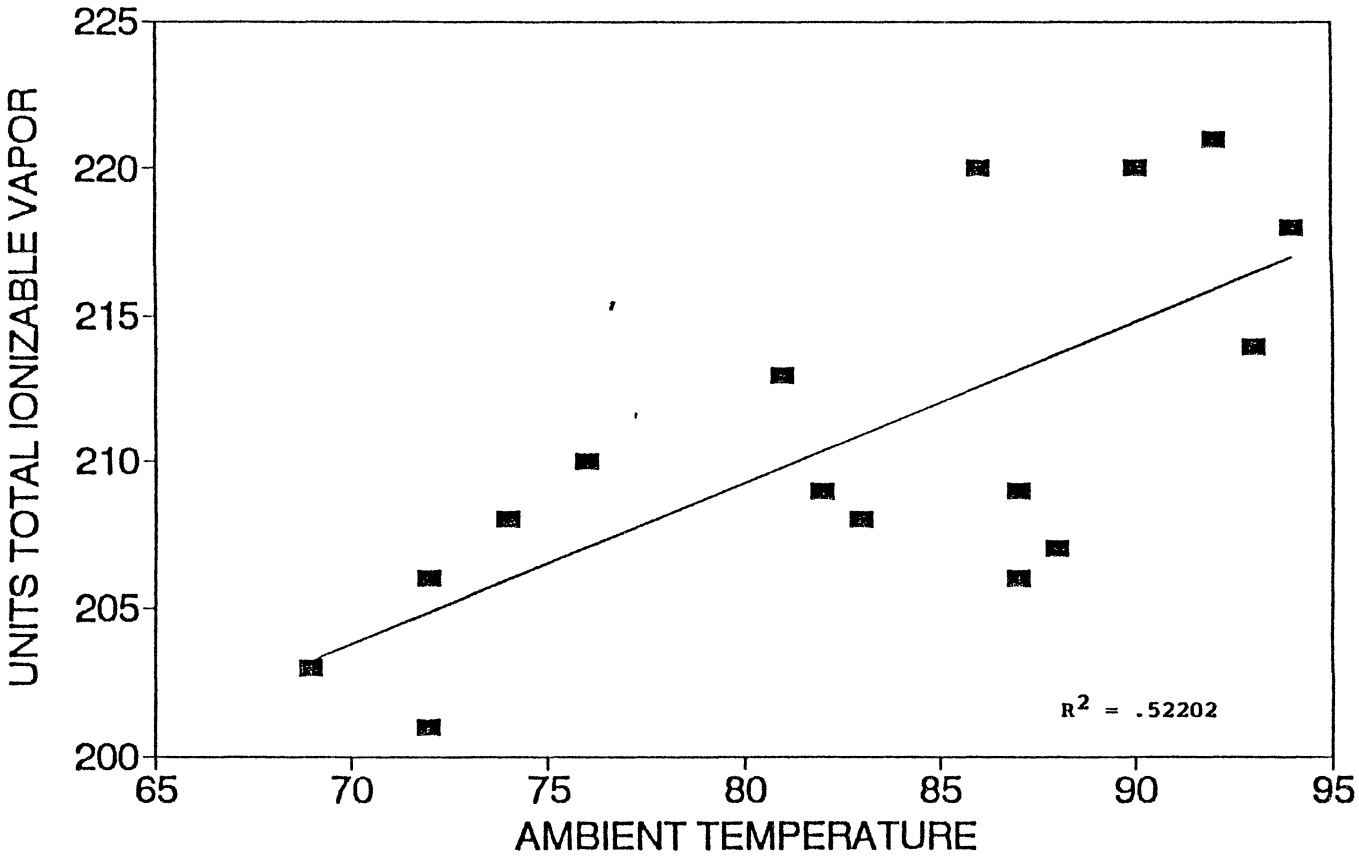


Figure 85. Scatter plot of TIV during diurnal study vs ambient temperature for SVP1

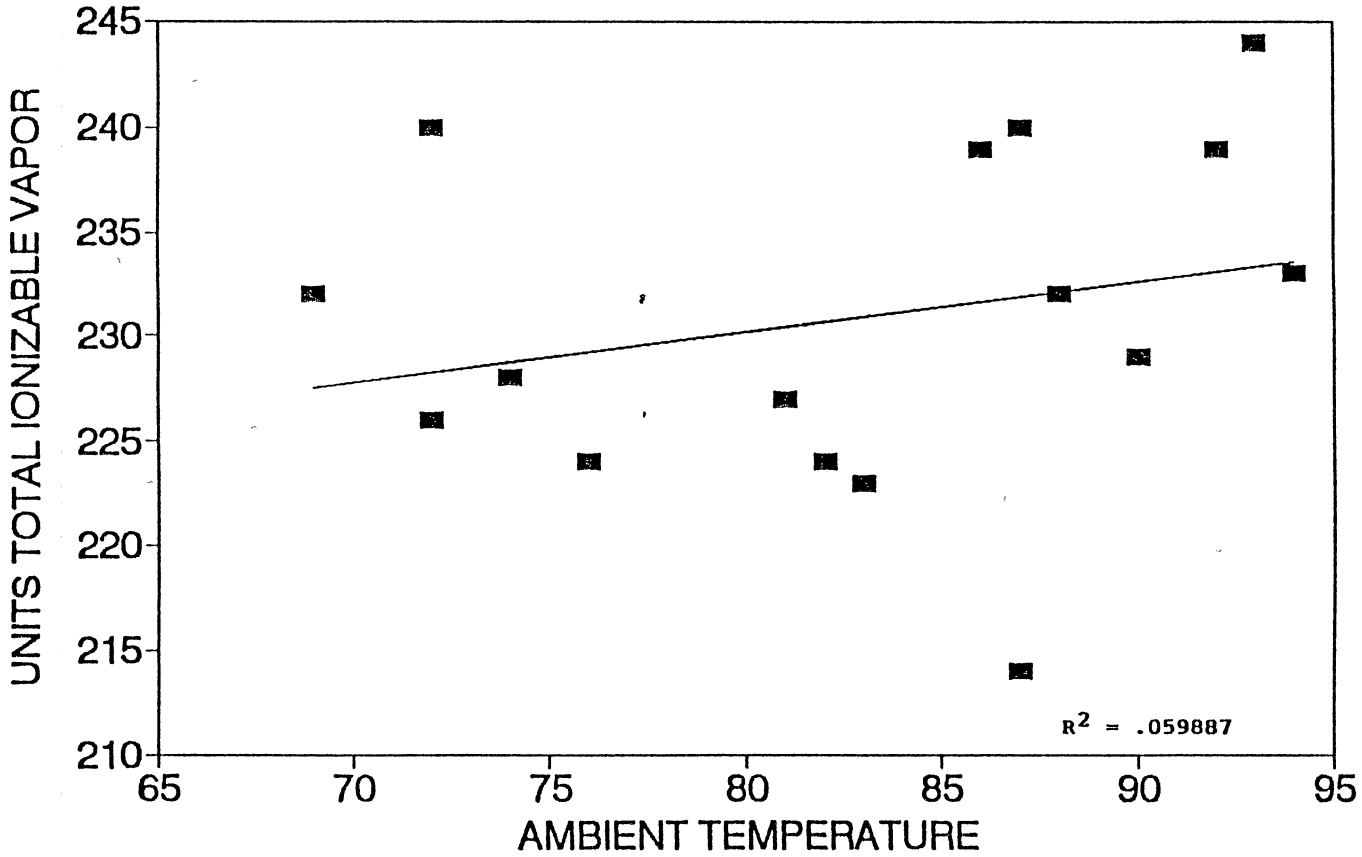


Figure 86. Scatter plot of TIV during diurnal study vs ambient temperature for SVP2

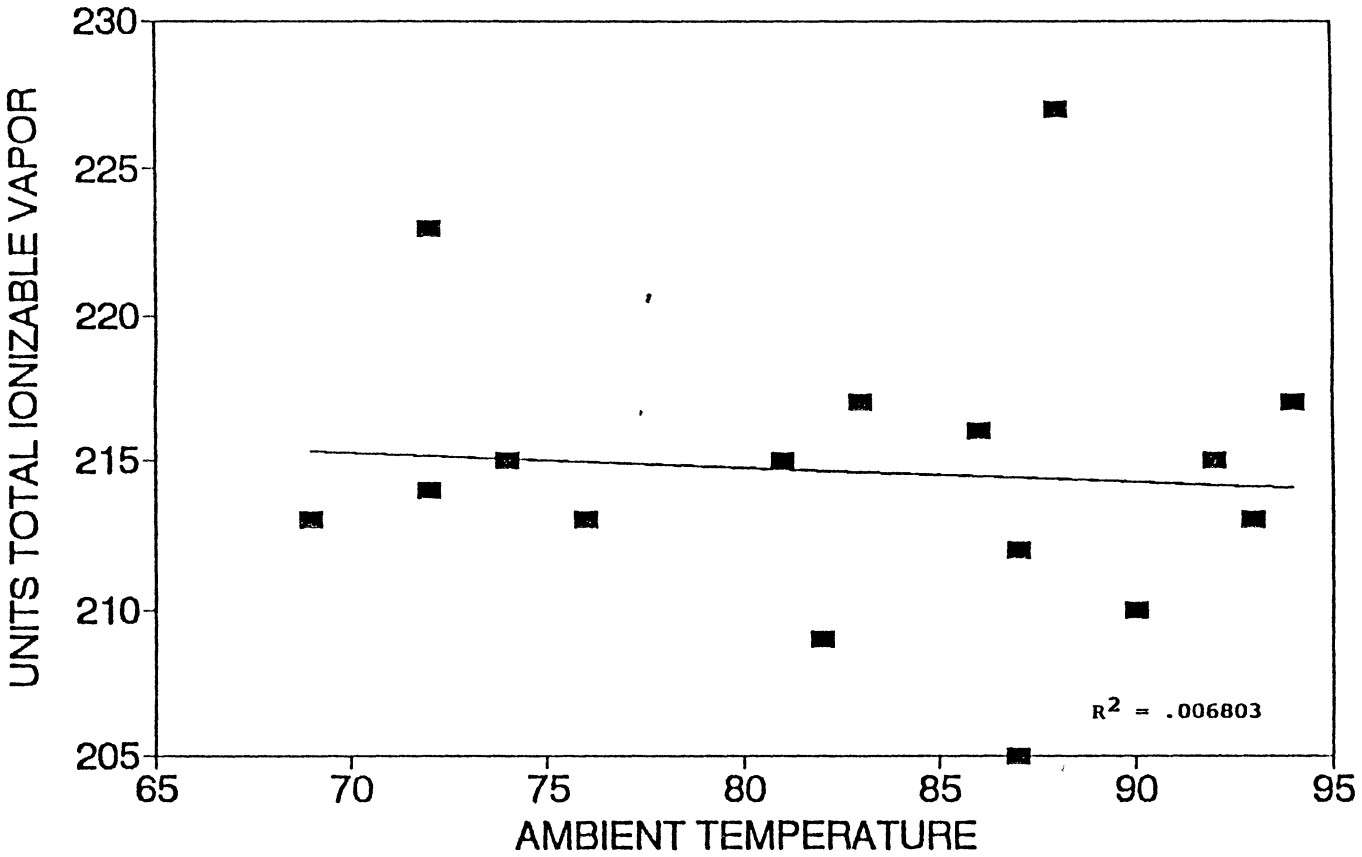


Figure 87. Scatter plot of TIV during diurnal study vs ambient temperature for SVP4

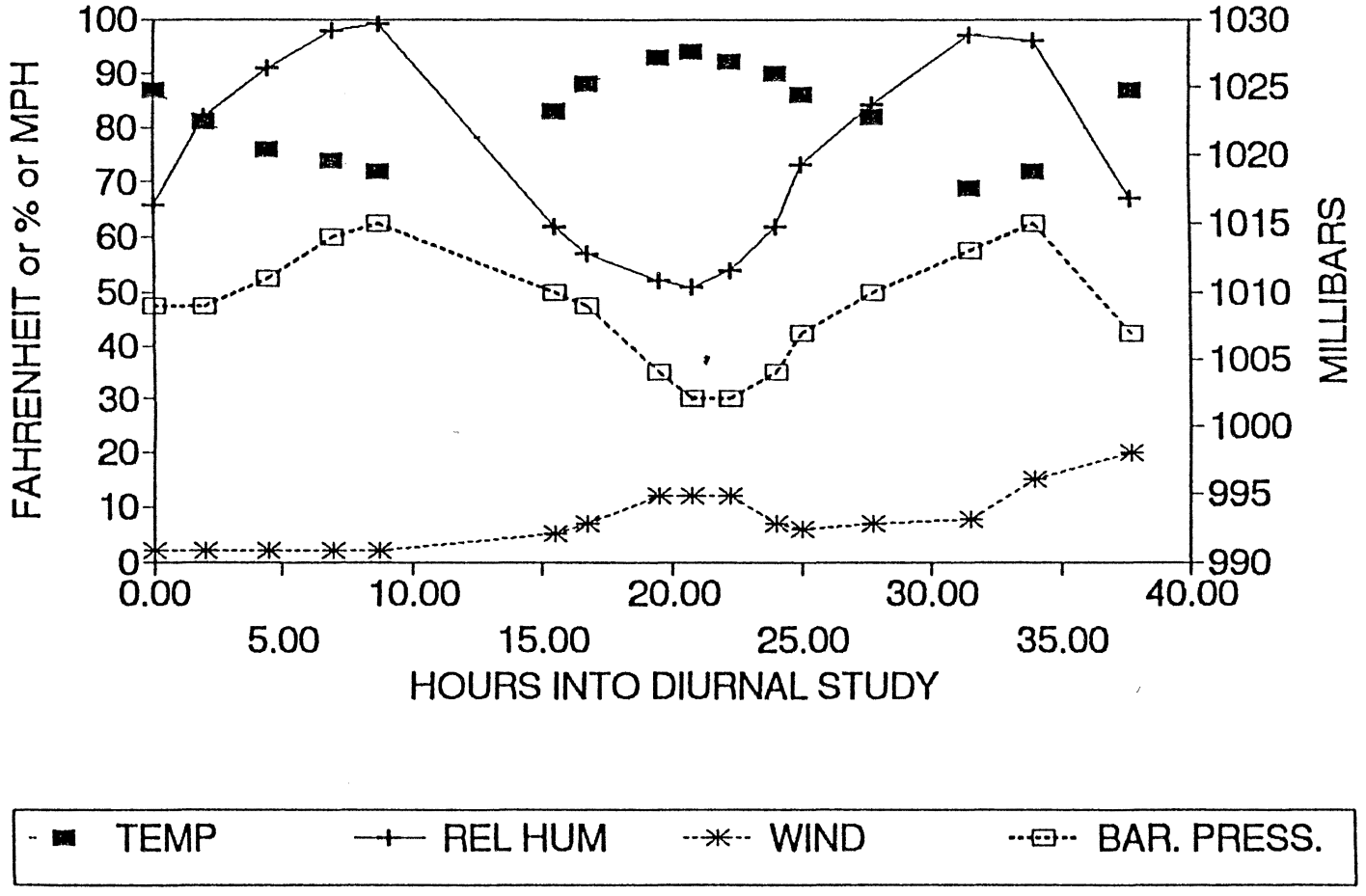


Figure 88. Weather variable values during diurnal study

Figures 89 through 97 are graphs showing the relationship of soil total ionizable vapors with barometric pressure change. For each sample point, there is an apparent visual negative relationship (that is, as barometric pressure rises, soil TIV values fall). The statistics for this relationship do not adequately verify any apparent linear relationship, as all the R2 values are well below .5. The diurnal measurements from vapor port 1 produced a good visual negative correlation between TIV and barometric pressure, with an R2 value of .715, while the correlations for the ports 2 and 4 measurements were a much poorer fit. The diurnal measurements from port 2 show a negative relationship for barometric pressure, but with a low R2 value (.116); port 4 shows a slightly positive relationship, with an even lower R2 value (.037).

Relative Humidity Effects

Increasing relative humidity will decrease the vapor pressure gradient from a water-saturated soil vapor to the atmosphere (soil vapor is almost always at or near saturation with respect to water vapor). As described by Henry's Law, gaseous diffusion will decrease in response to a decreased vapor pressure gradient. Thus soil vapor movement and organic vapor concentration would be expected to be diminished as relative humidity increases. However, since soil vapor is essentially always between 98 to 100 percent relative humidity, the effects of changing

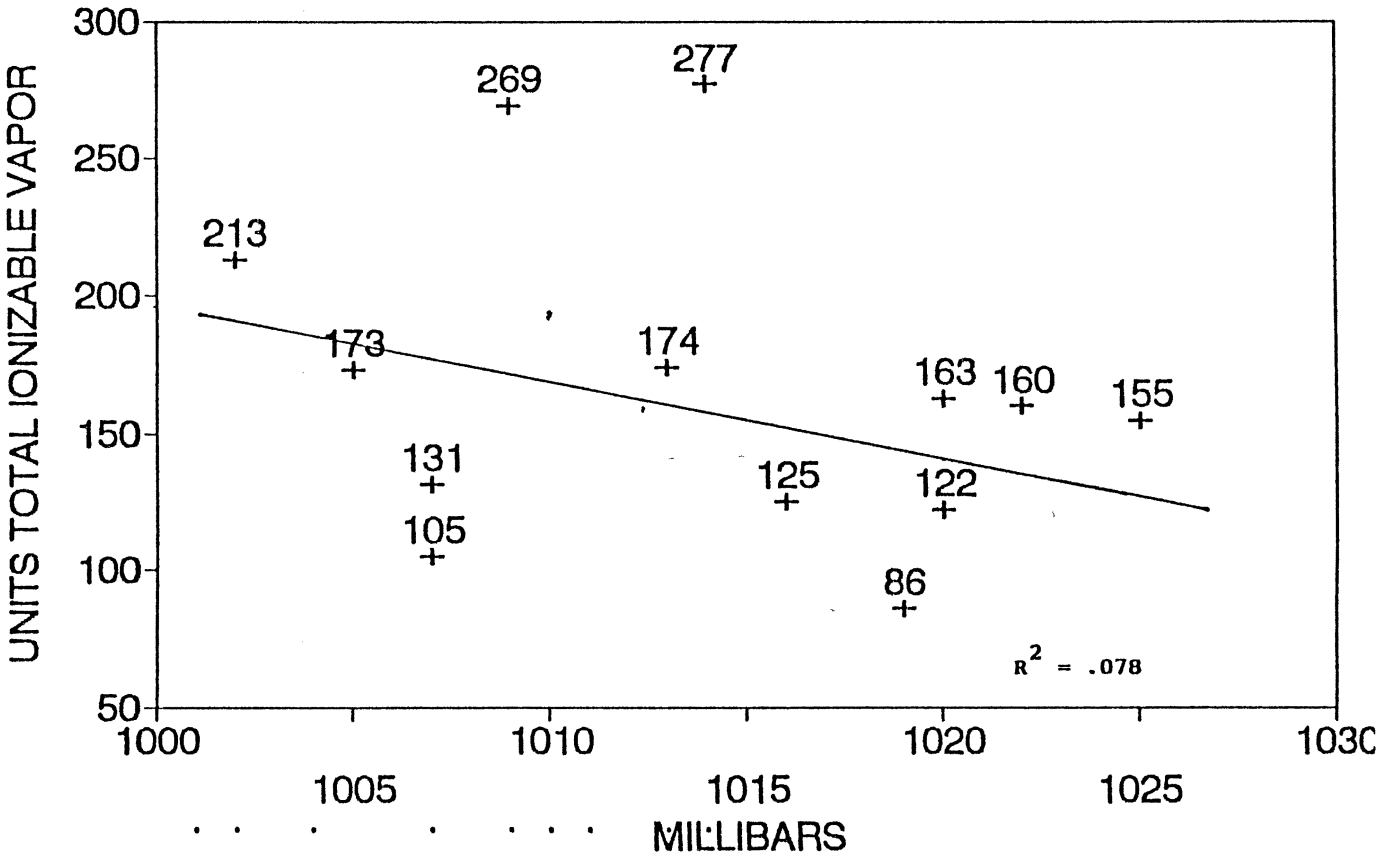


Figure 89. Scatter plot of TIV vs barometric pressure in core holes at sample point 1, with regression line

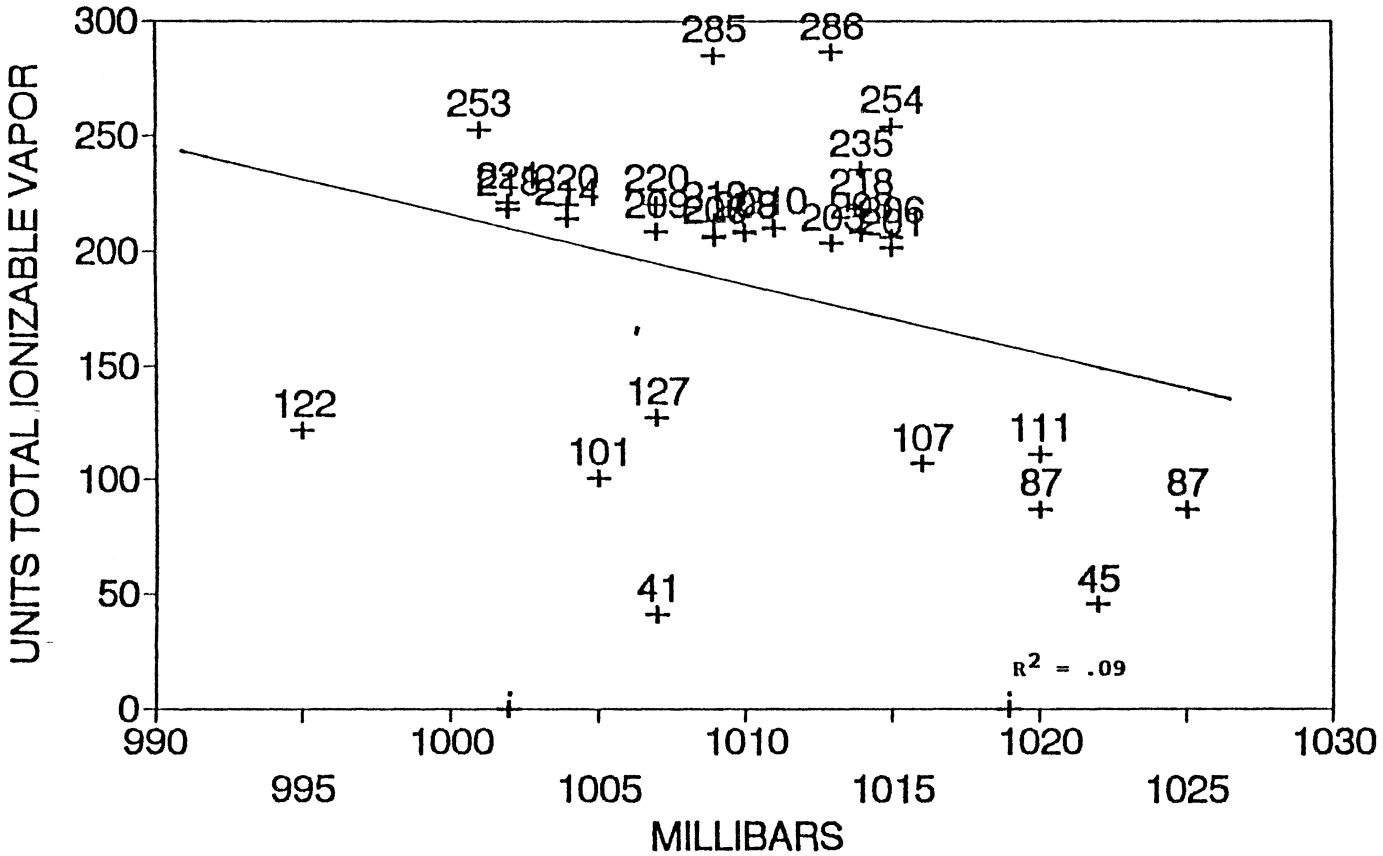


Figure 90. Scatter plot of TIV vs barometric pressure in soil vapor port 1, with regression line

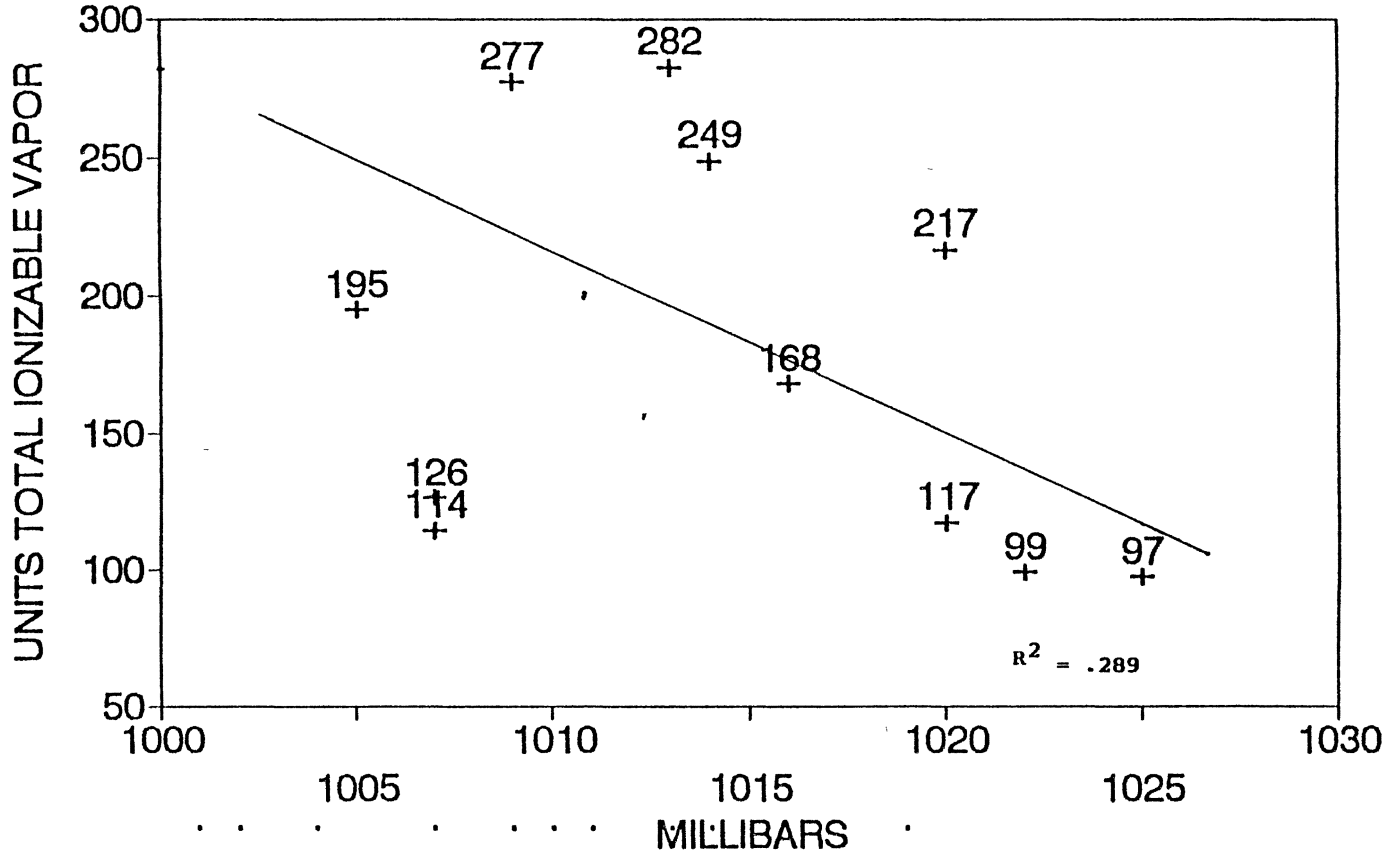


Figure 91. Scatter plot of TIV vs barometric pressure in core holes at sample point 2, with regression line

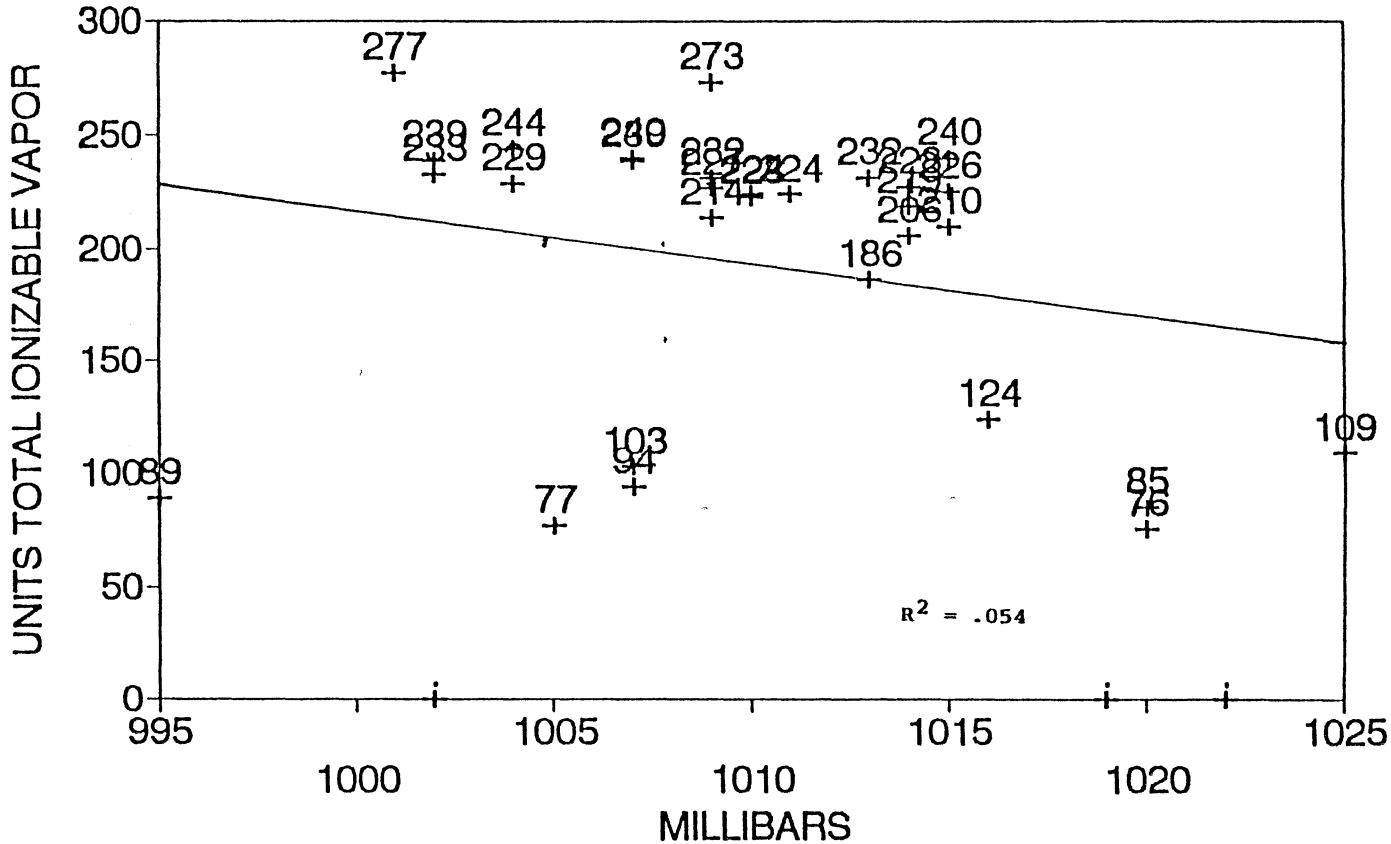


Figure 92. Scatter plot of TIV vs barometric pressure in soil vapor port 2, with regression line

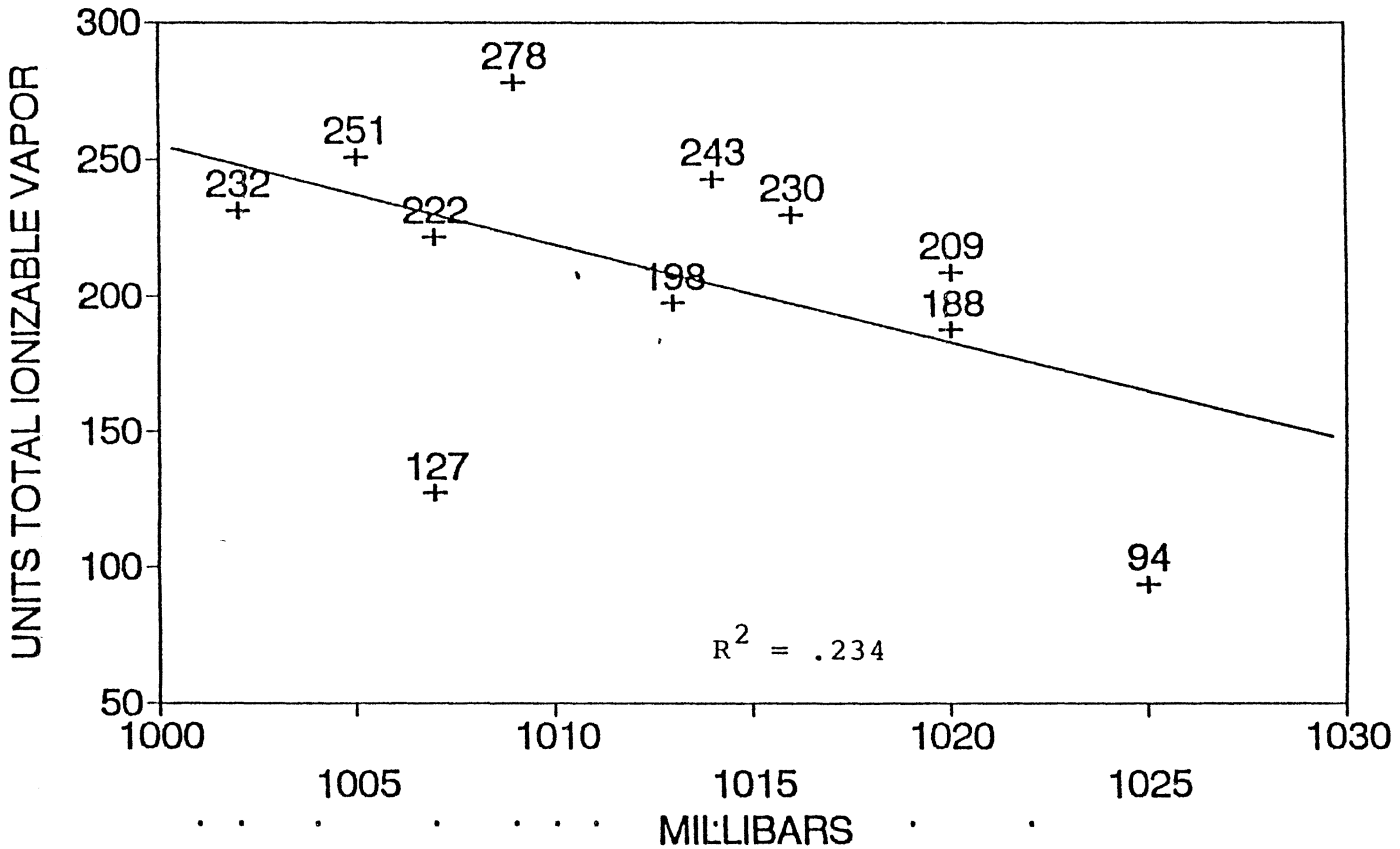


Figure 93. Scatter plot of TIV vs barometric pressure in core holes at sample point 4, with regression line

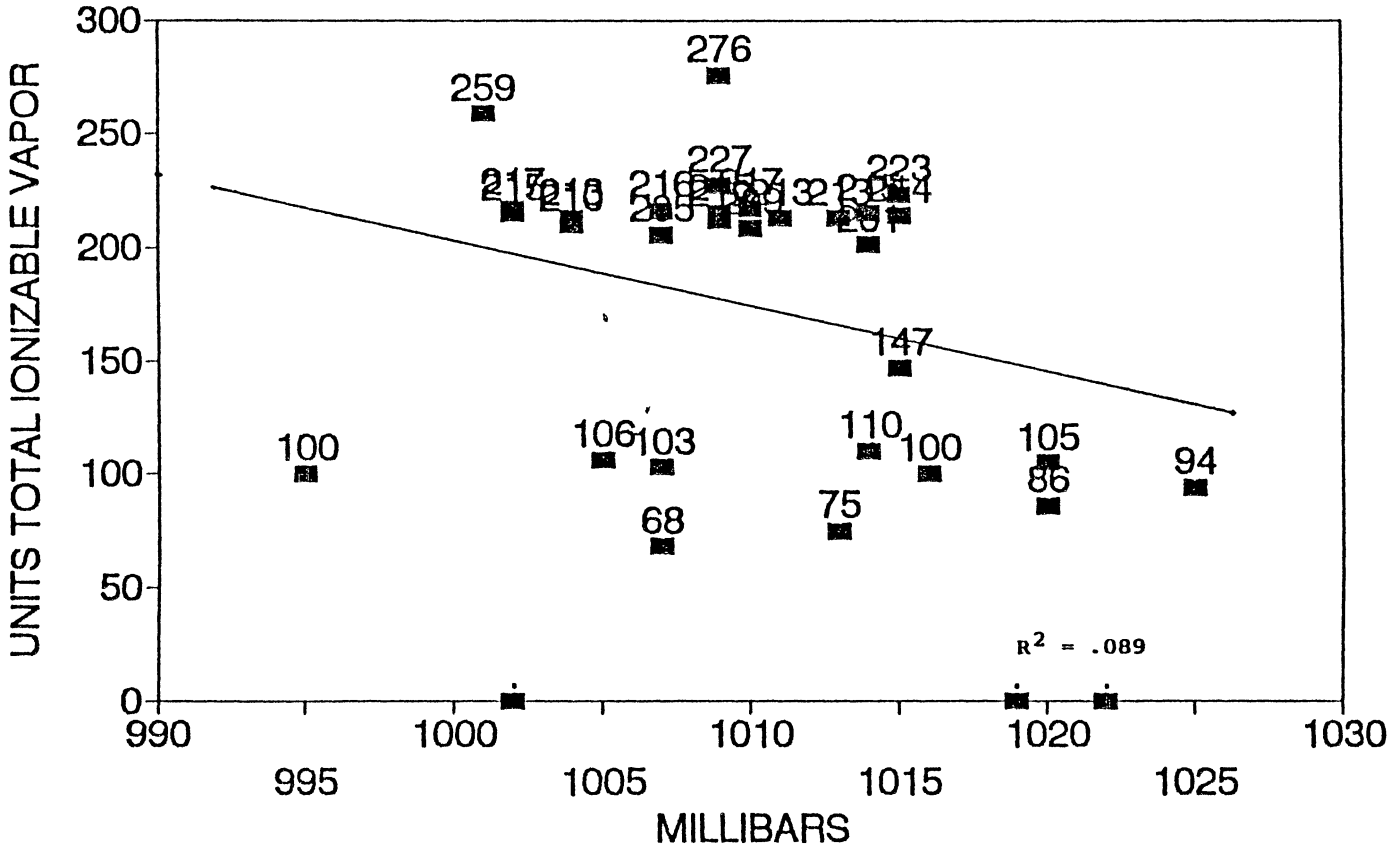


Figure 94. Scatter plot of TIV vs barometric pressure in soil vapor port 4, with regression line

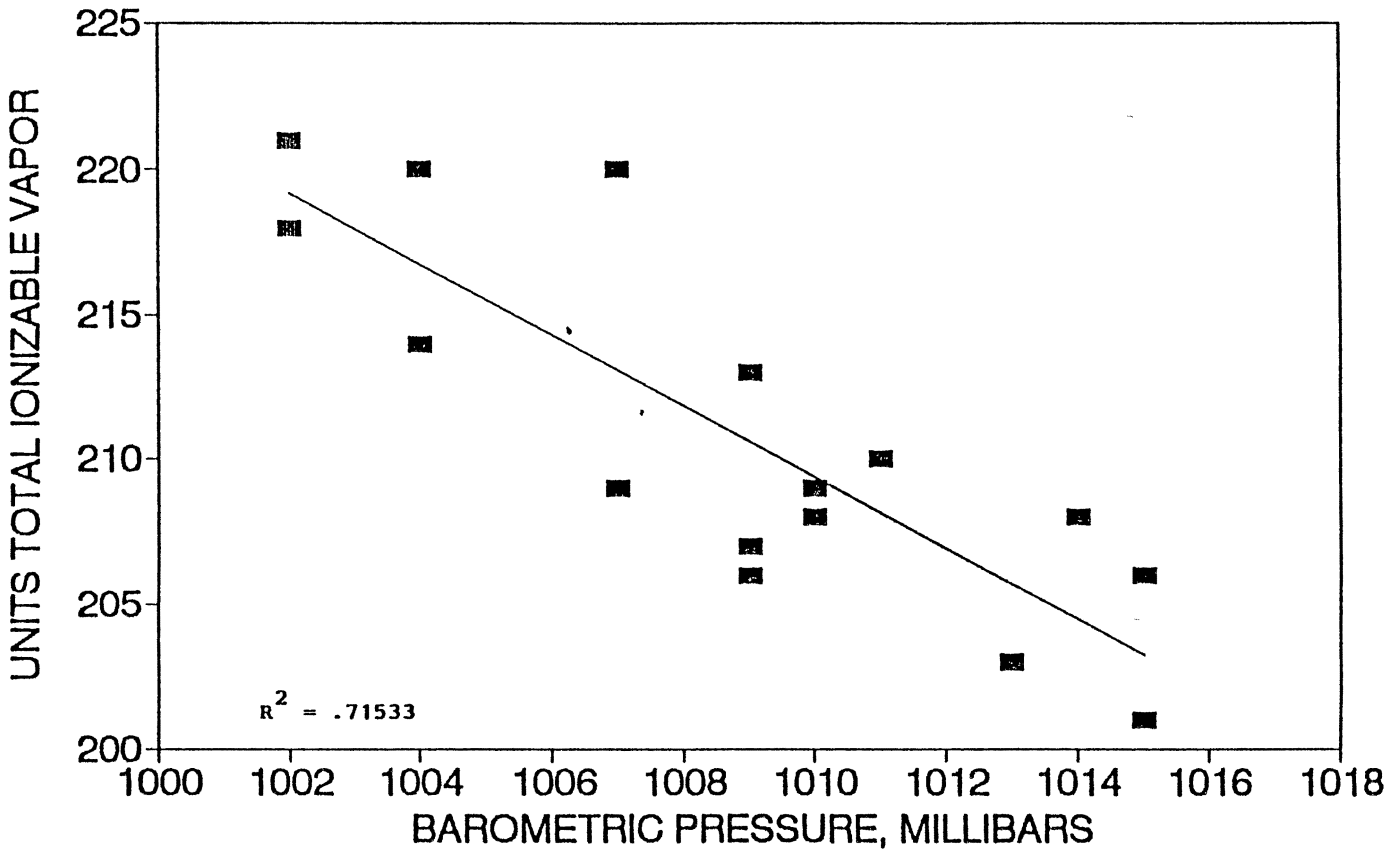


Figure 95. Scatter plot of TIV during diurnal study vs barometric pressure for SVP1

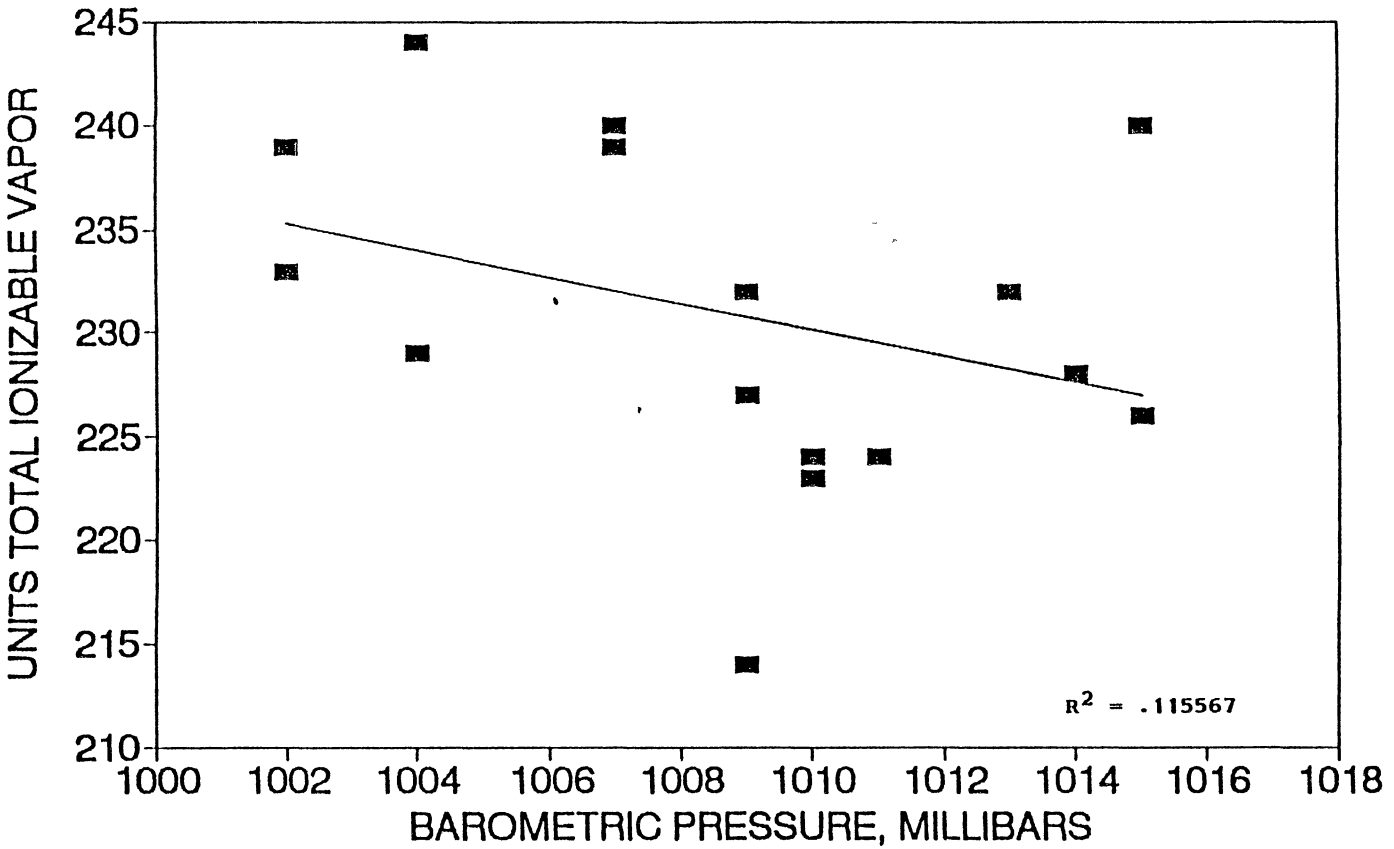


Figure 96. Scatter plot of TIV during diurnal study vs barometric pressure for SVP2

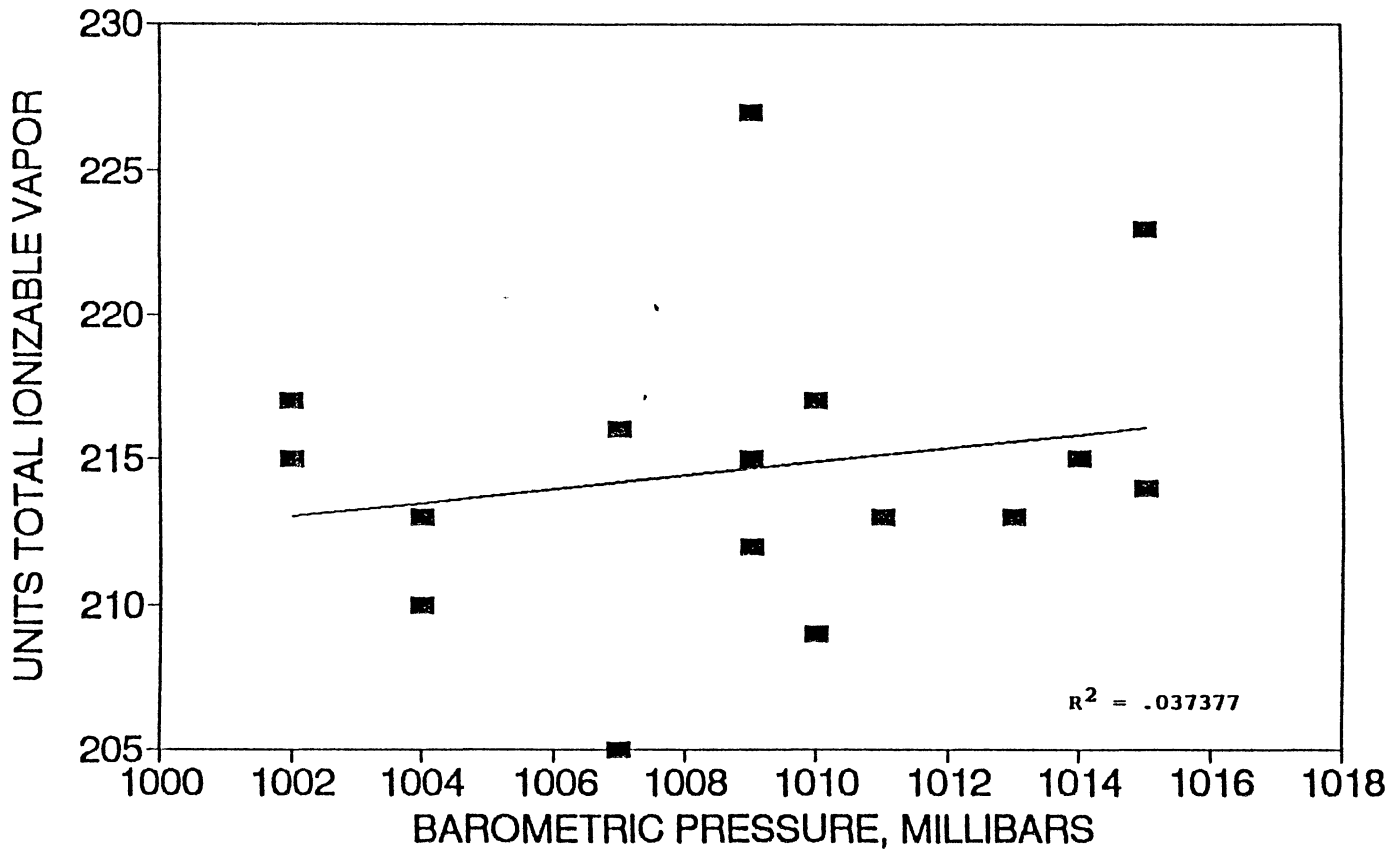


Figure 97. Scatter plot of TIV during diurnal study vs barometric pressure for SVP4

atmospheric relative humidity would not be expected to have a very large effect on soil volatile organic vapor concentration, especially at depths where daily temperature fluctuation are insignificant.

Figures 98 through 106 illustrate that over the long term, the correlation between long term change in ambient relative humidity and soil vapor concentration appears visually to be positive; however the R2 values for these lines are all very low. A probable reason for the apparent positive correlation may be seen by Figure 75, (page 172) which shows the long-term trends in weather variables measured with collection of vapor samples: relative humidity has increased with seasonal change, very much like temperature has increased. This long-term trend appears to have over-ridden any other observable effects from changes in relative humidity.

The short-term data, however, show a negative correlation between relative humidity and soil organic vapor concentration, again with low R2 values for each vapor port data set (.366 for SVP1, .002 for SVP2 and .059 for SVP4). The visual negative correlation for diurnal relative humidity change and soil vapor concentration is most likely a correlative effect with barometric pressure change, which is parallel with relative humidity in the diurnal cycle, as shown by Figure 88.

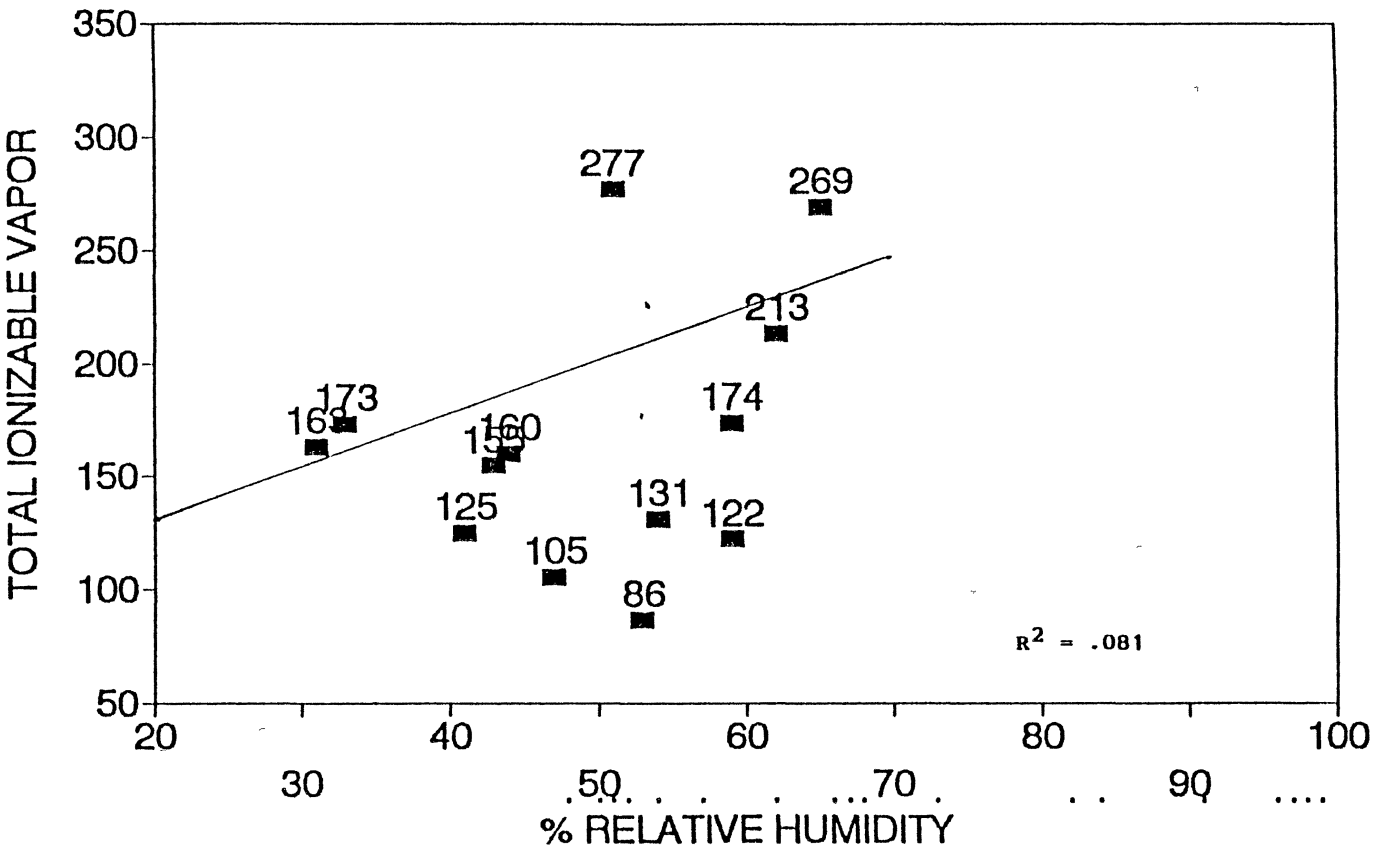


Figure 98. Scatter plot of TIV vs relative humidity in core holes at sample point 1, with regression line

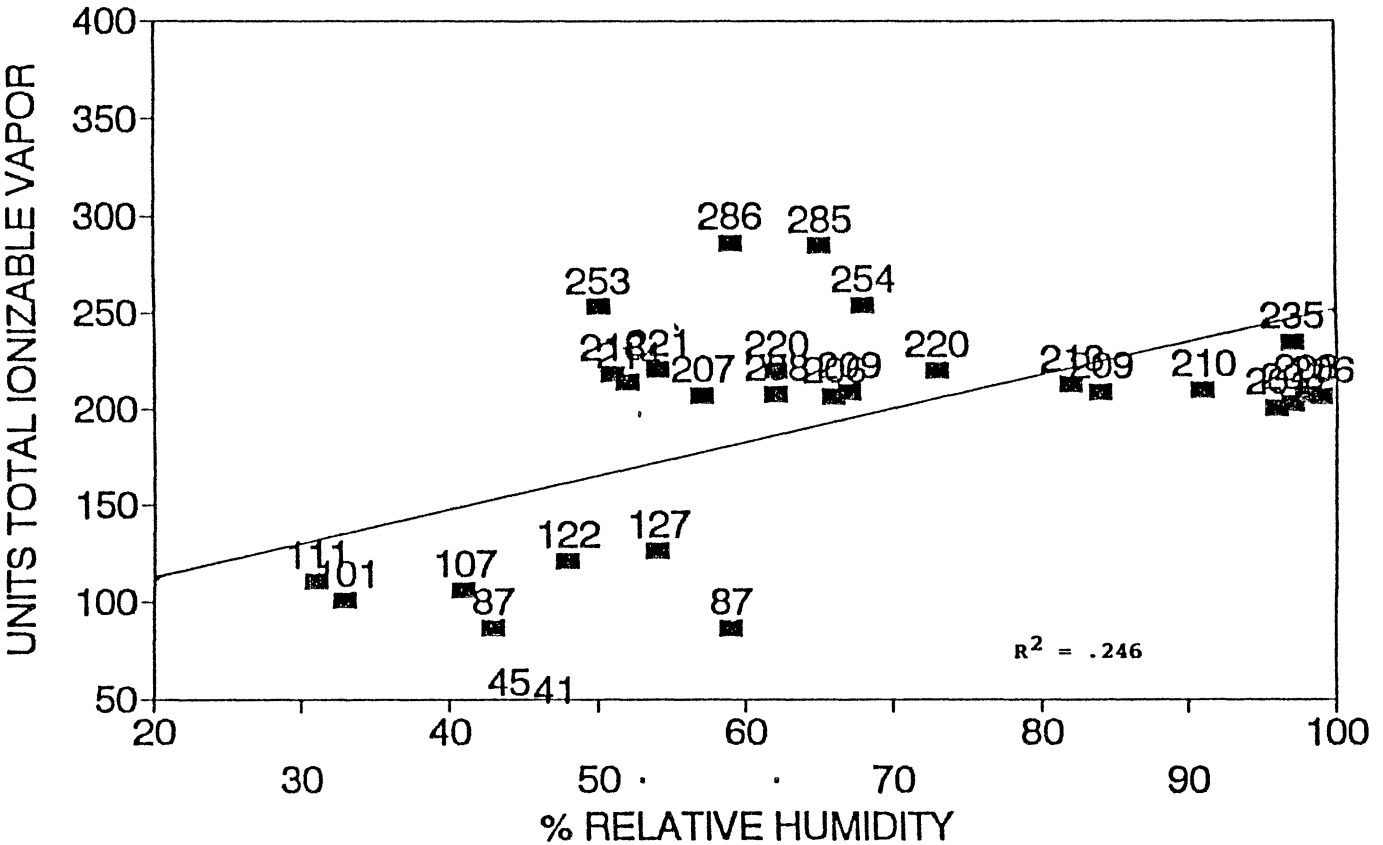


Figure 99. Scatter plot of TIV vs relative humidity in soil vapor port 1, with regression line

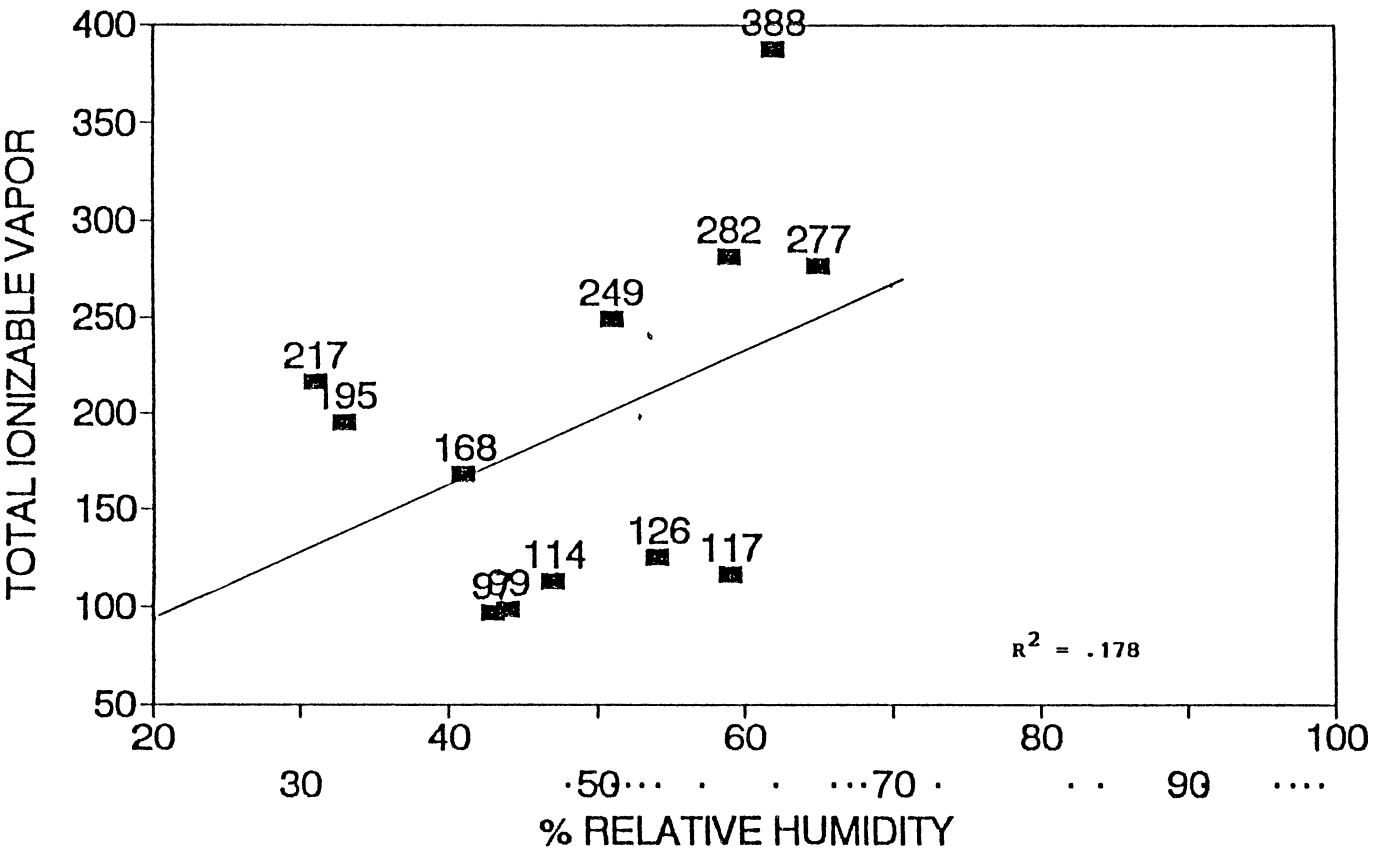


Figure 100. Scatter plot of TIV vs relative humidity in core holes at sample point 2, with regression line

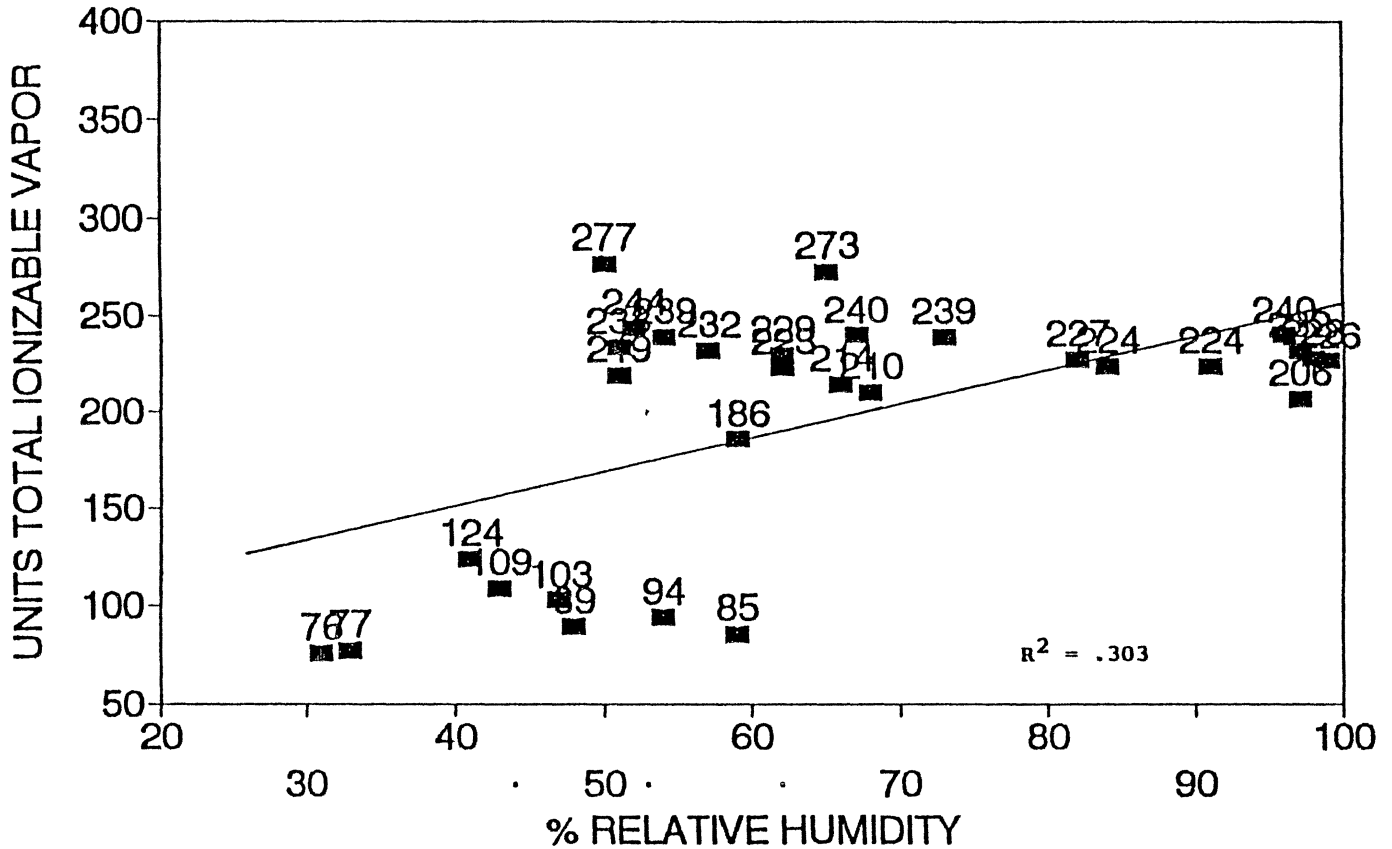


Figure 101. Scatter plot of TIV vs relative humidity in soil vapor port 2, with regression line

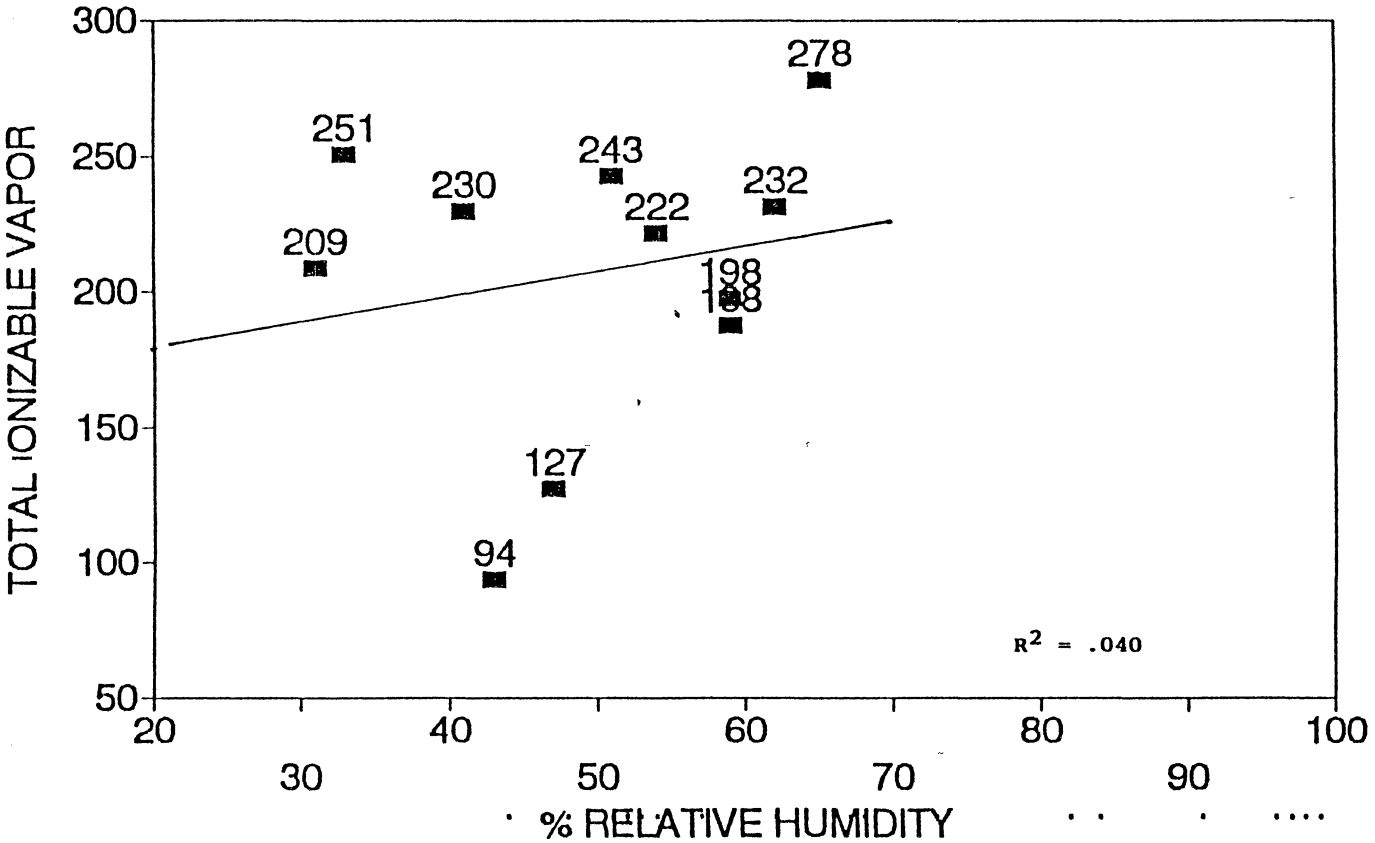


Figure 102. Scatter plot of TIV vs relative humidity in core holes at sample point 4, with regression line

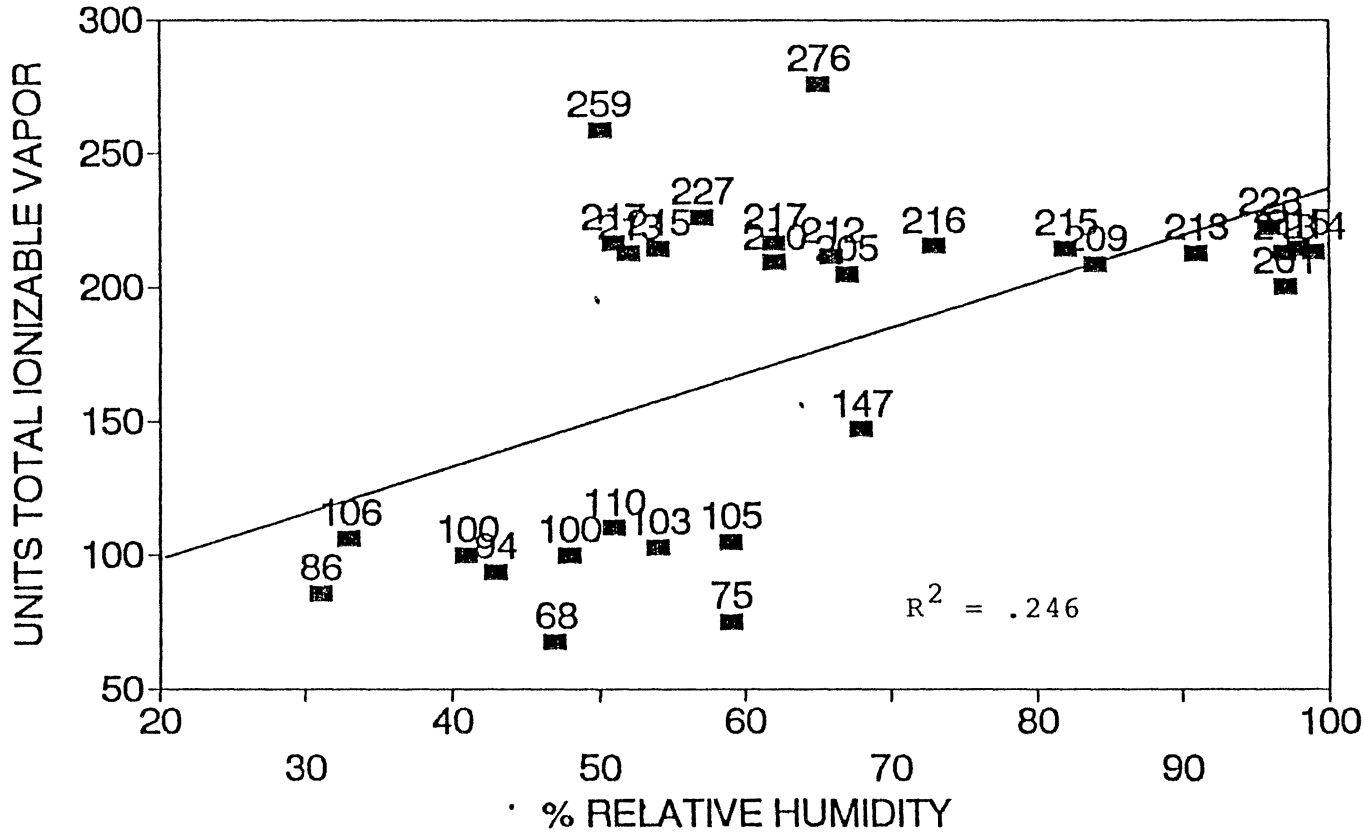


Figure 103. Scatter plot of TIV vs relative humidity in soil vapor port 4, with regression line

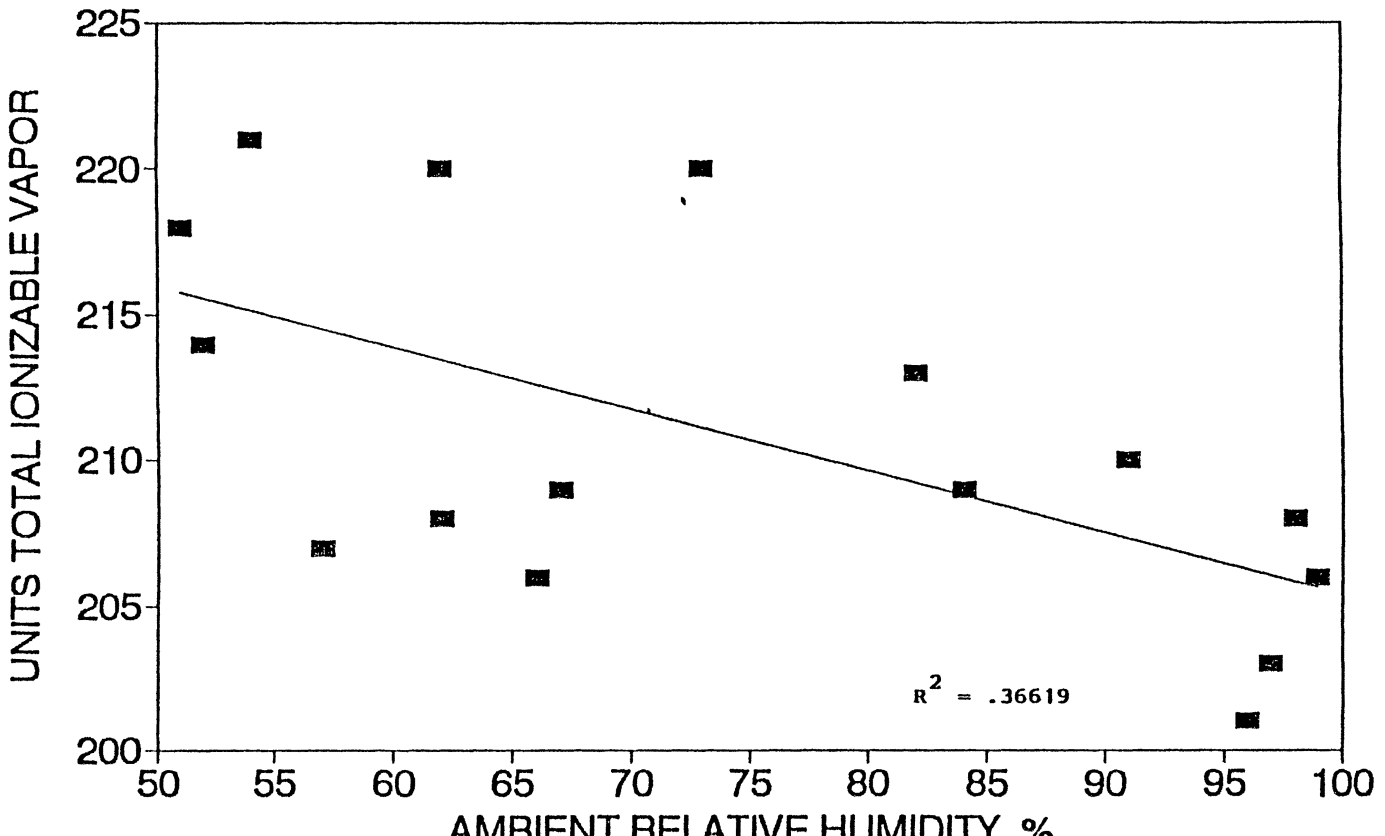


Figure 104. Scatter plot of TIV during diurnal study vs relative humidity for SVP1

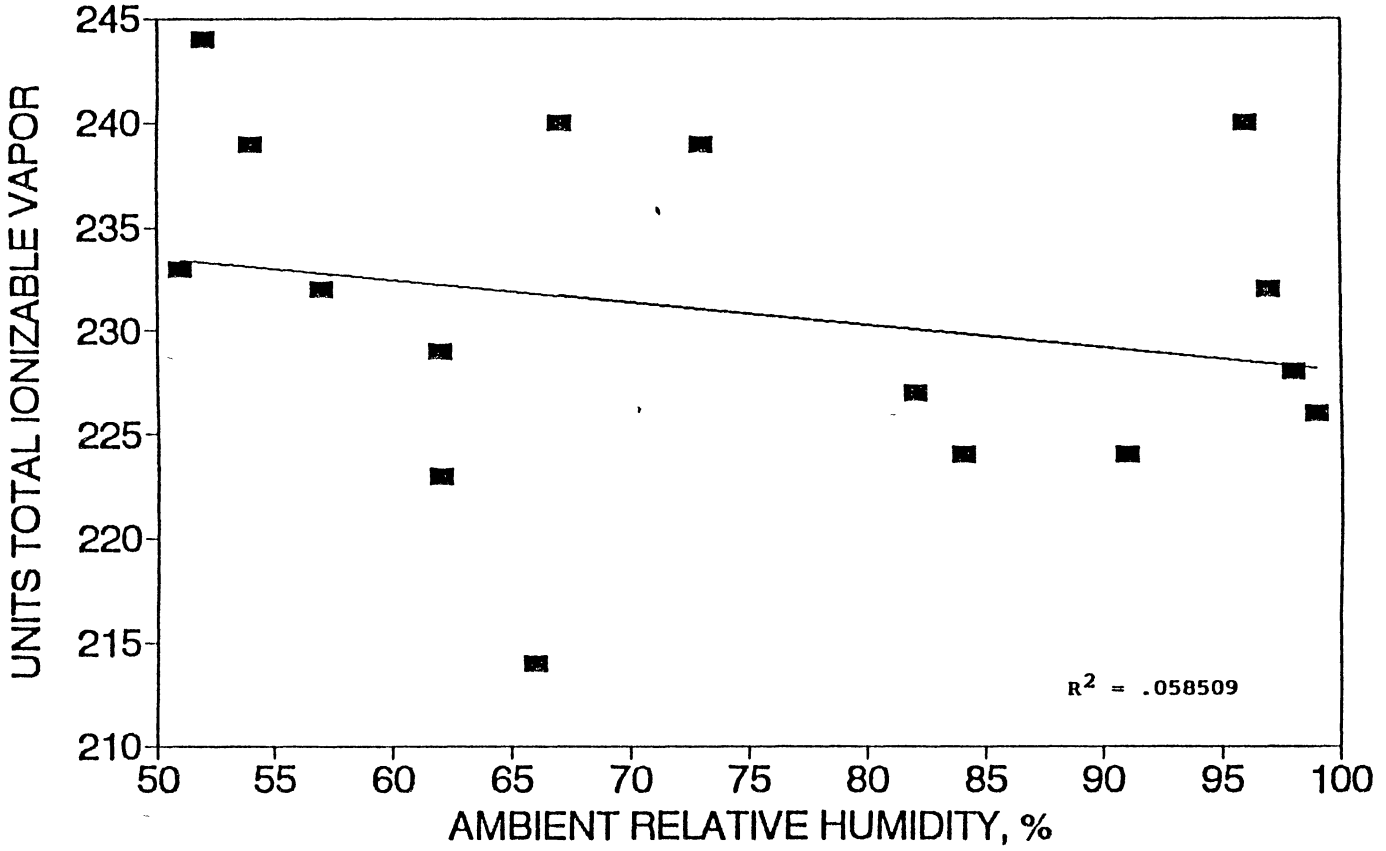


Figure 105. Scatter plot of TIV during diurnal study vs relative humidity for SVP2

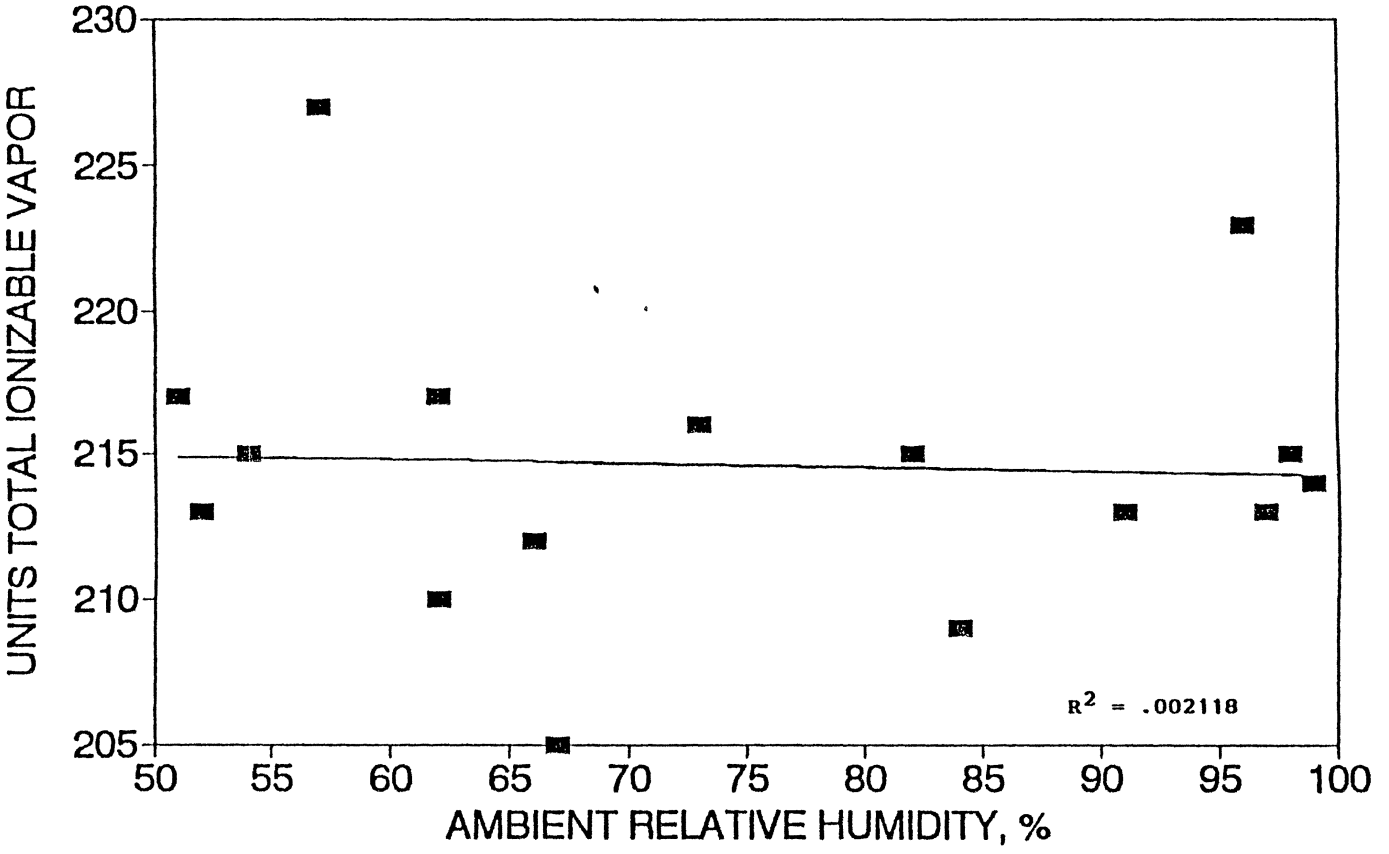


Figure 106. Scatter plot of TIV during diurnal study vs relative humidity for SVP4

Wind Speed Effects

Wind speed would be expected to have a positive correlation with soil organic vapor concentration, by creating a pressure drop at the land surface, which conceptually would increase the pressure gradient and increase volatilization. High wind speeds in combination with low barometric pressure has been documented to increase vapor concentration in enclosed areas from a gasoline-contaminated ground water source (Reichmuth, 1984). This effect would probably be insignificant at normal wind speeds, however.

Figures 107 through 112 show the linear regression lines for the long-term wind speed and soil vapor concentration data for each sample point. While the points on these graphs are grouped fairly tightly, there appears to be very little change in TIV values with wind speed. The regression lines fit poorly for all these lines, and R2 values are correspondingly very low. Coefficients are positive for most sample points but negative for others. In all, there seems little evidence for a significant effect from wind speed in the long-term data.

The diurnal data plots (Figures 113 through 115) look equally indeterminate for SVP1 and SVP4, with R2 values of .008 and .009, respectively. SVP2, however, shows a fairly good positive correlation, with an R2 value of .58. If any wind effect were observed, it would produce the strongest

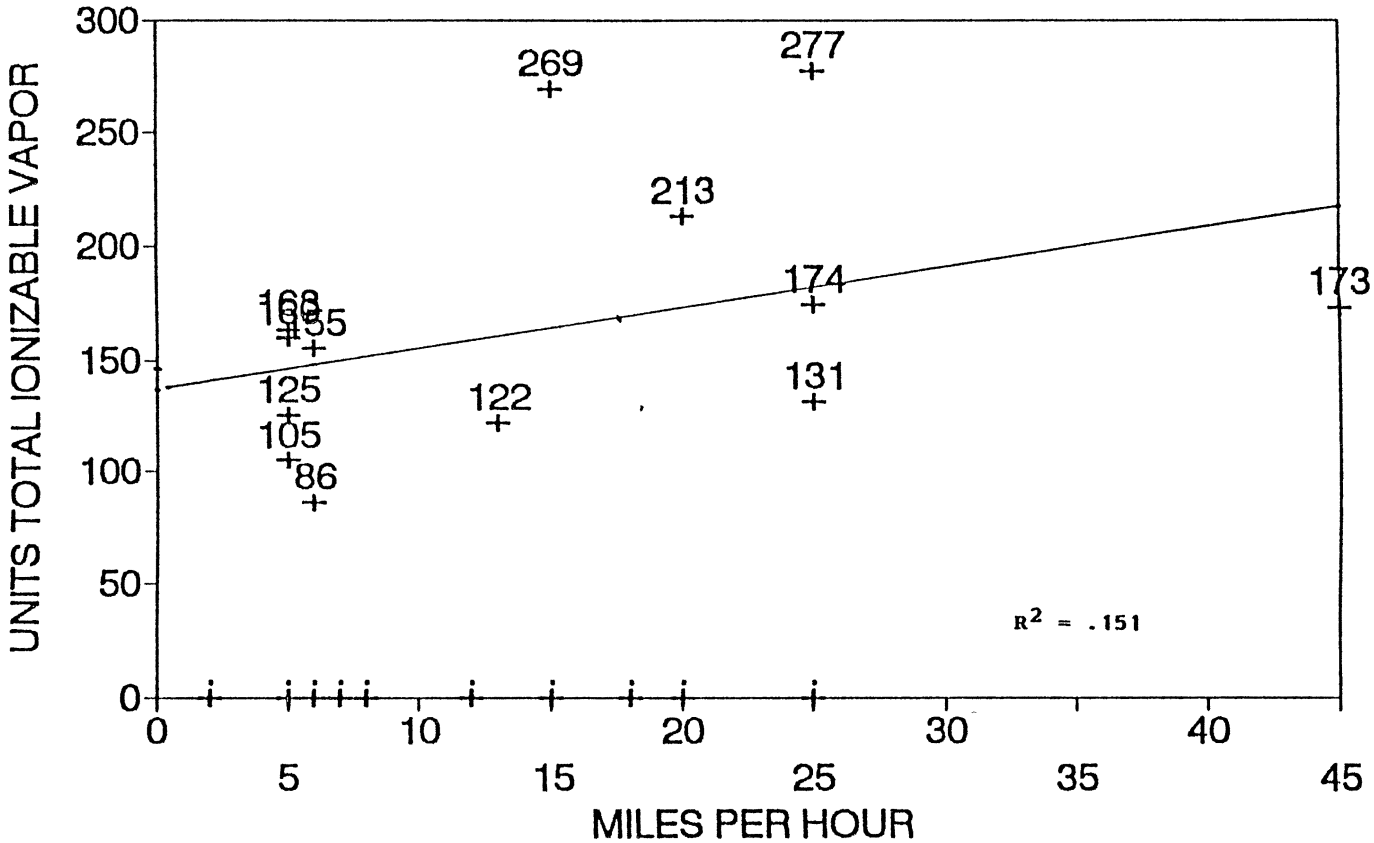


Figure 107. Scatter plot of TIV vs wind speed in core holes at sample point 1, with regression line

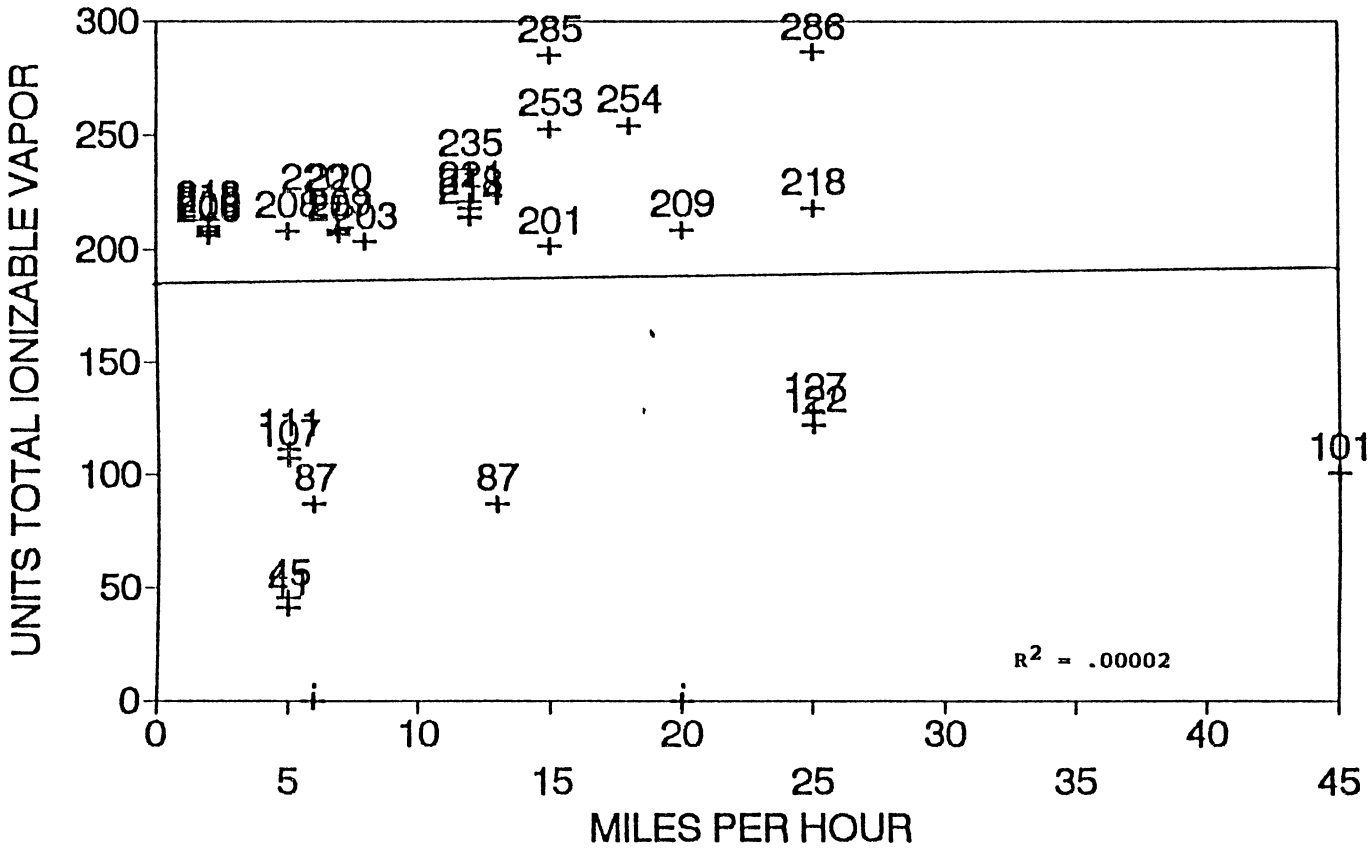


Figure 108. Scatter plot of TIV vs wind speed in soil vapor port 1, with regression line

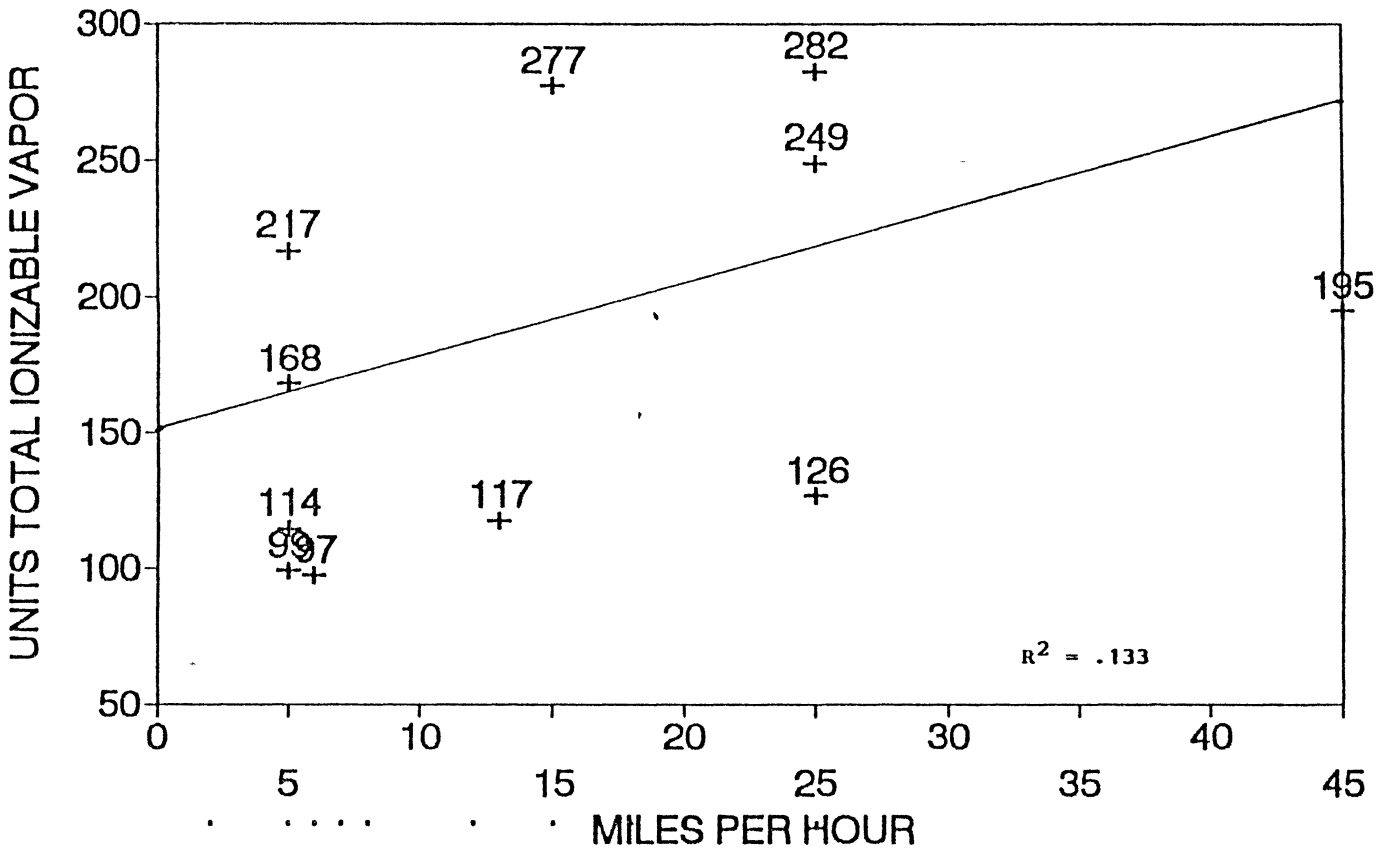


Figure 109. Scatter plot of TIV vs wind speed in core holes at sample point 2, with regression line

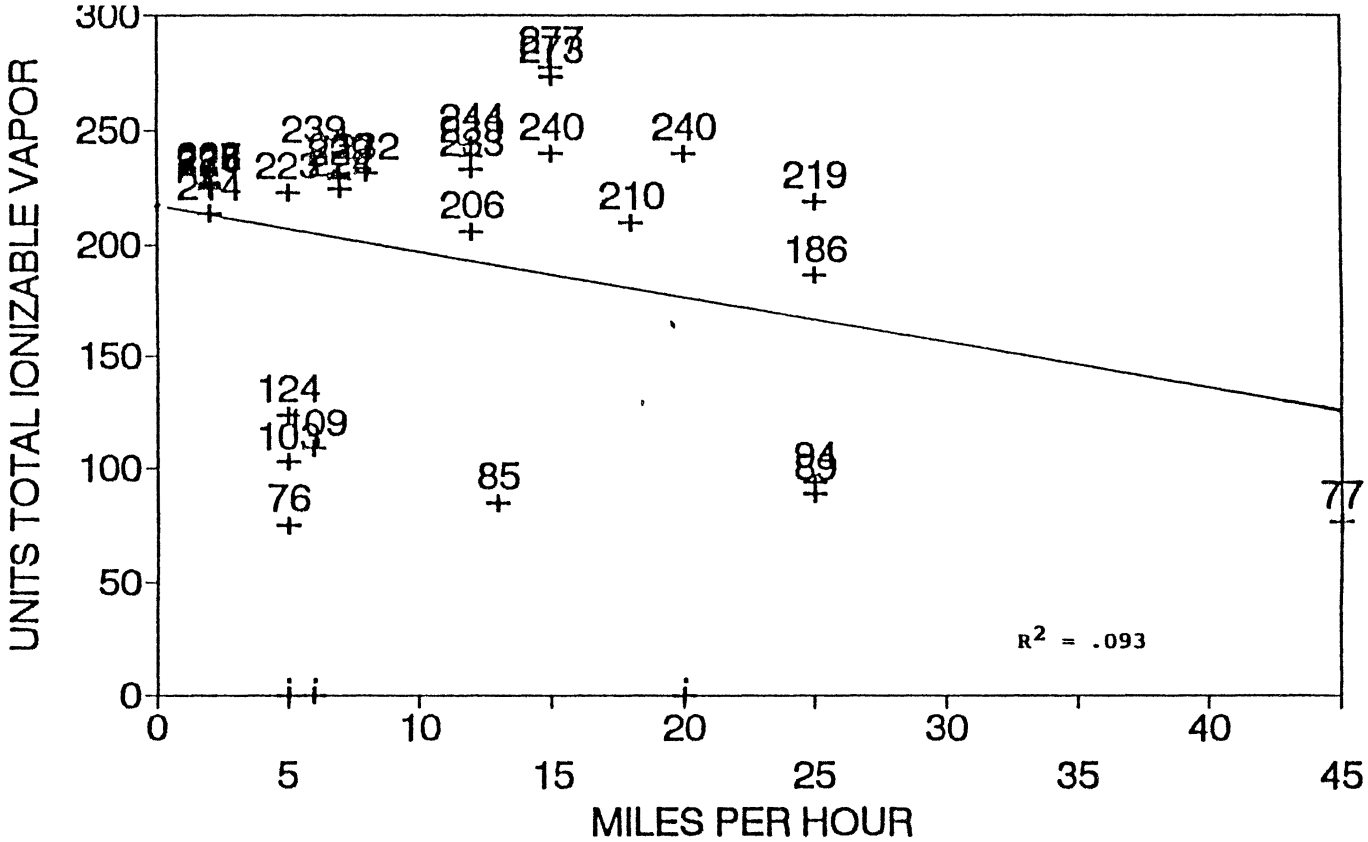


Figure 110. Scatter plot of TIV vs wind speed in soil vapor port 2, with regression line

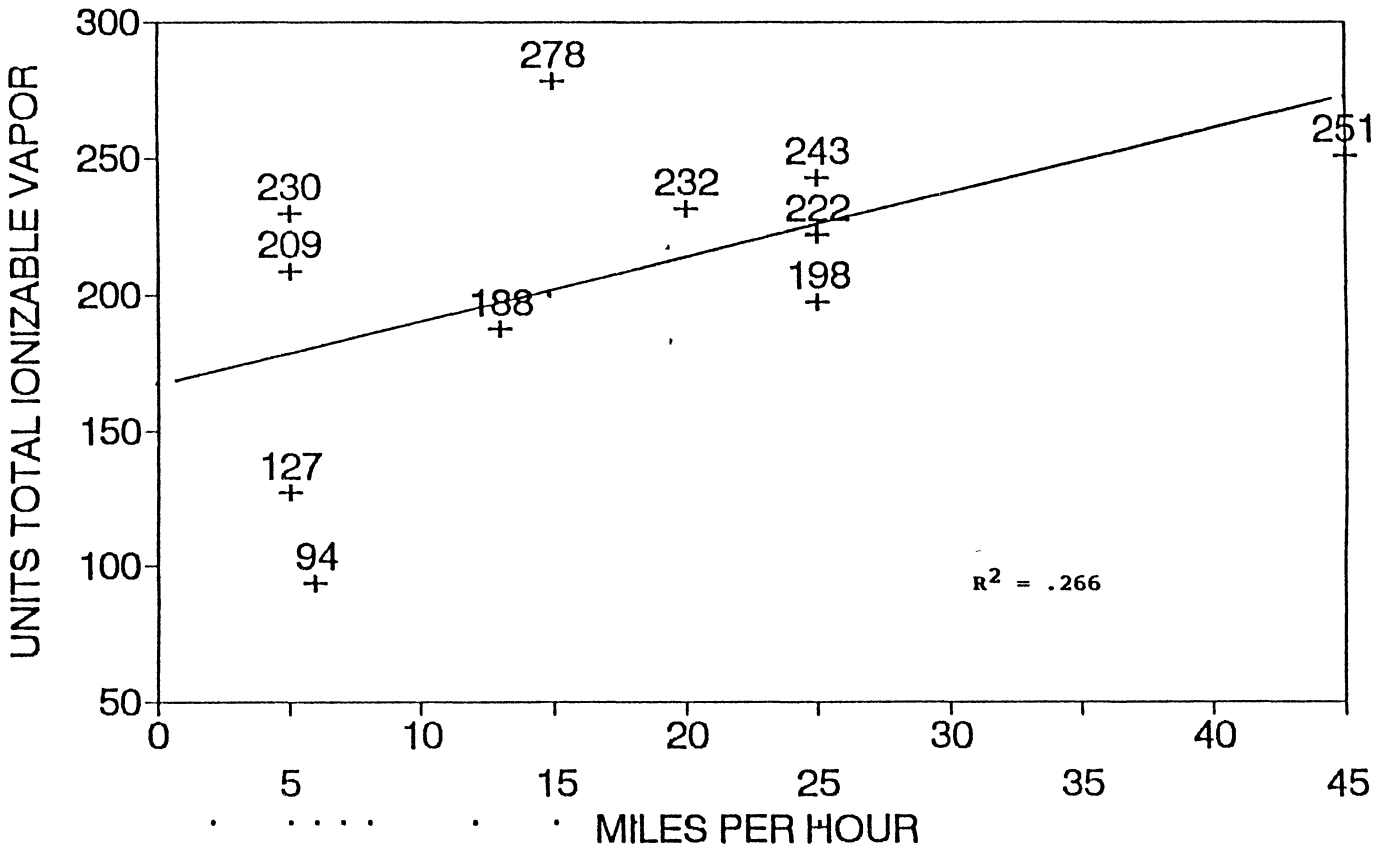


Figure 111. Scatter plot of TIV vs wind speed in core holes at sample point 4, with regression line

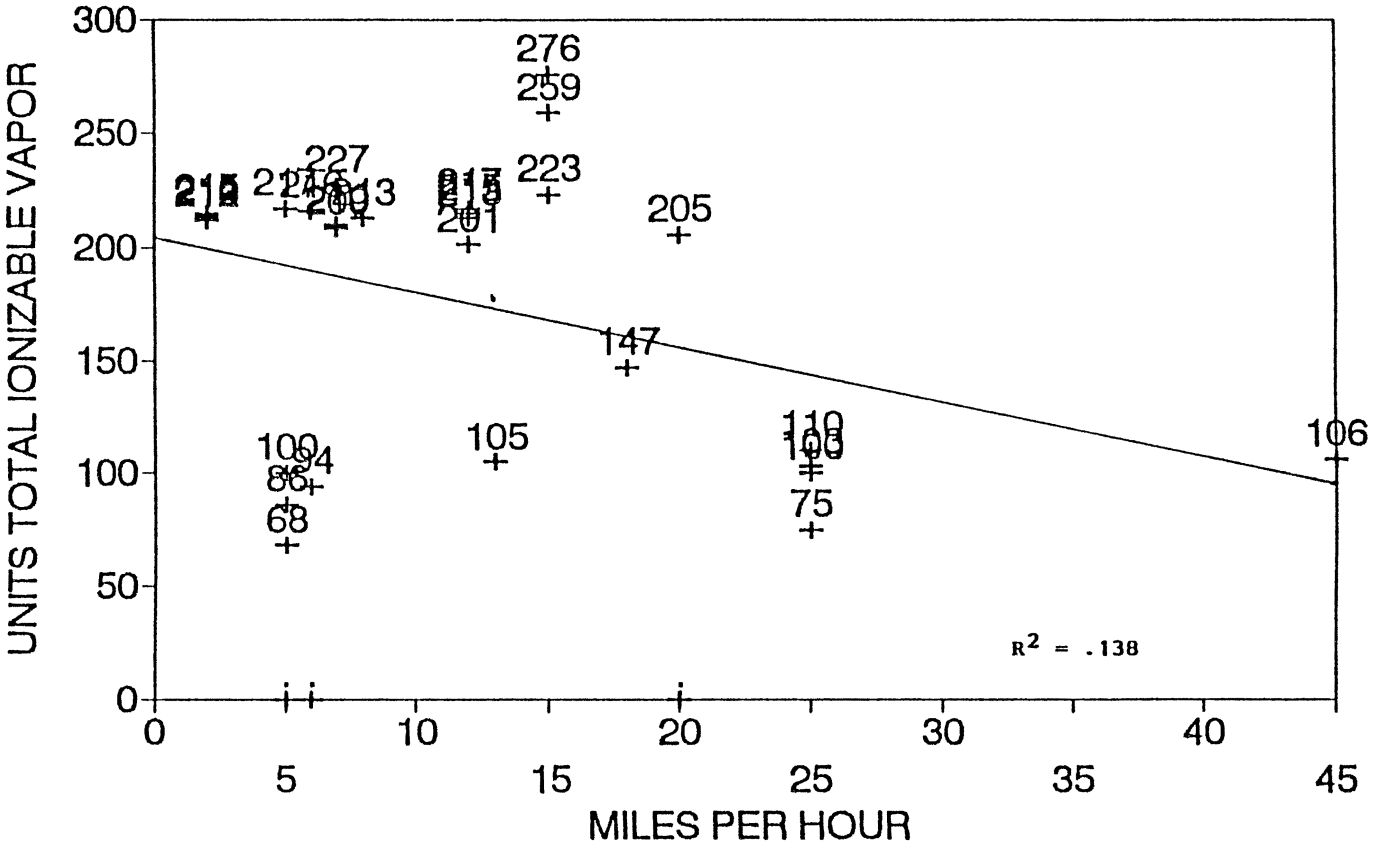


Figure 112. Scatter plot of TIV vs wind speed in soil vapor port 4, with regression line

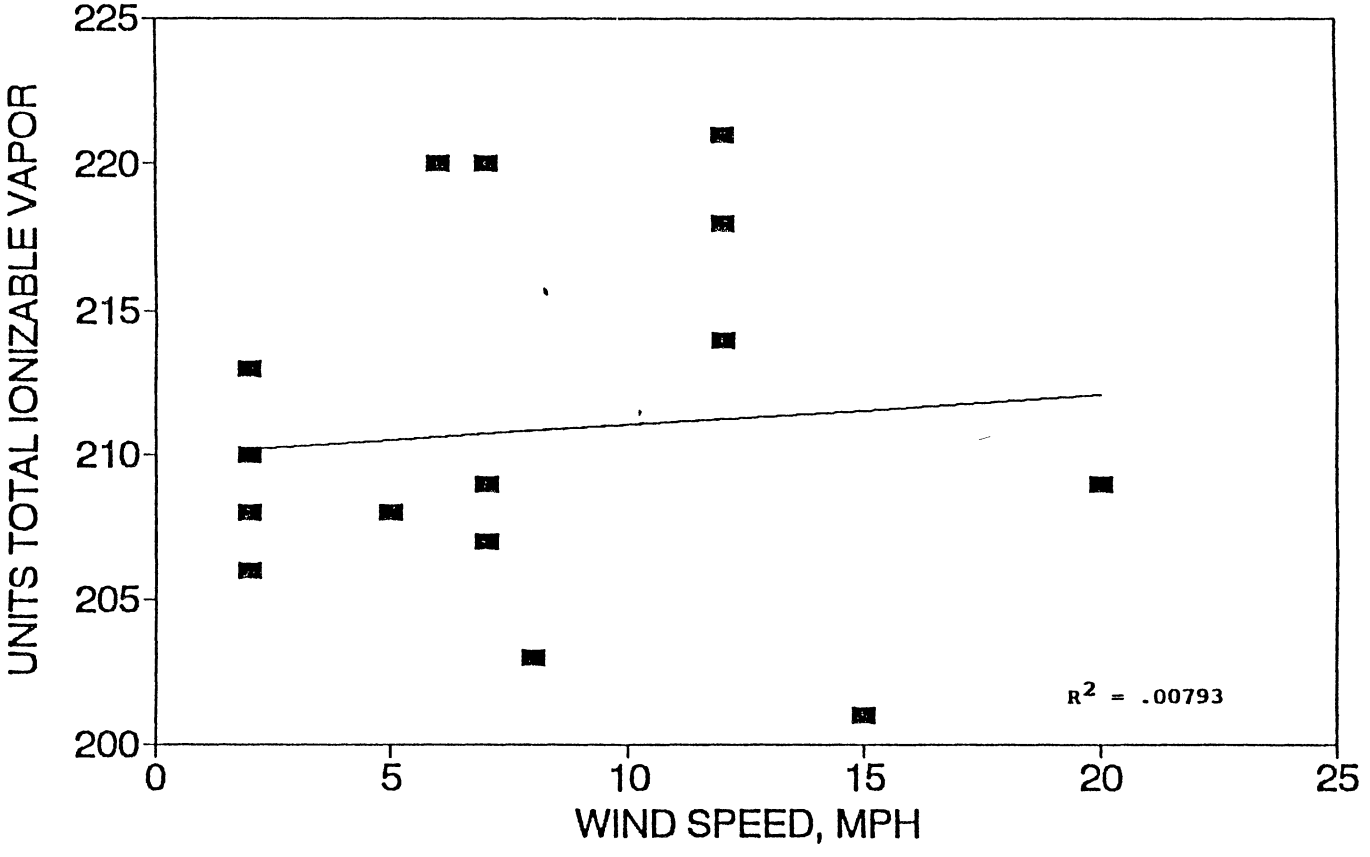


Figure 113. Scatter plot of TIV during diurnal study vs wind speed for SVP1

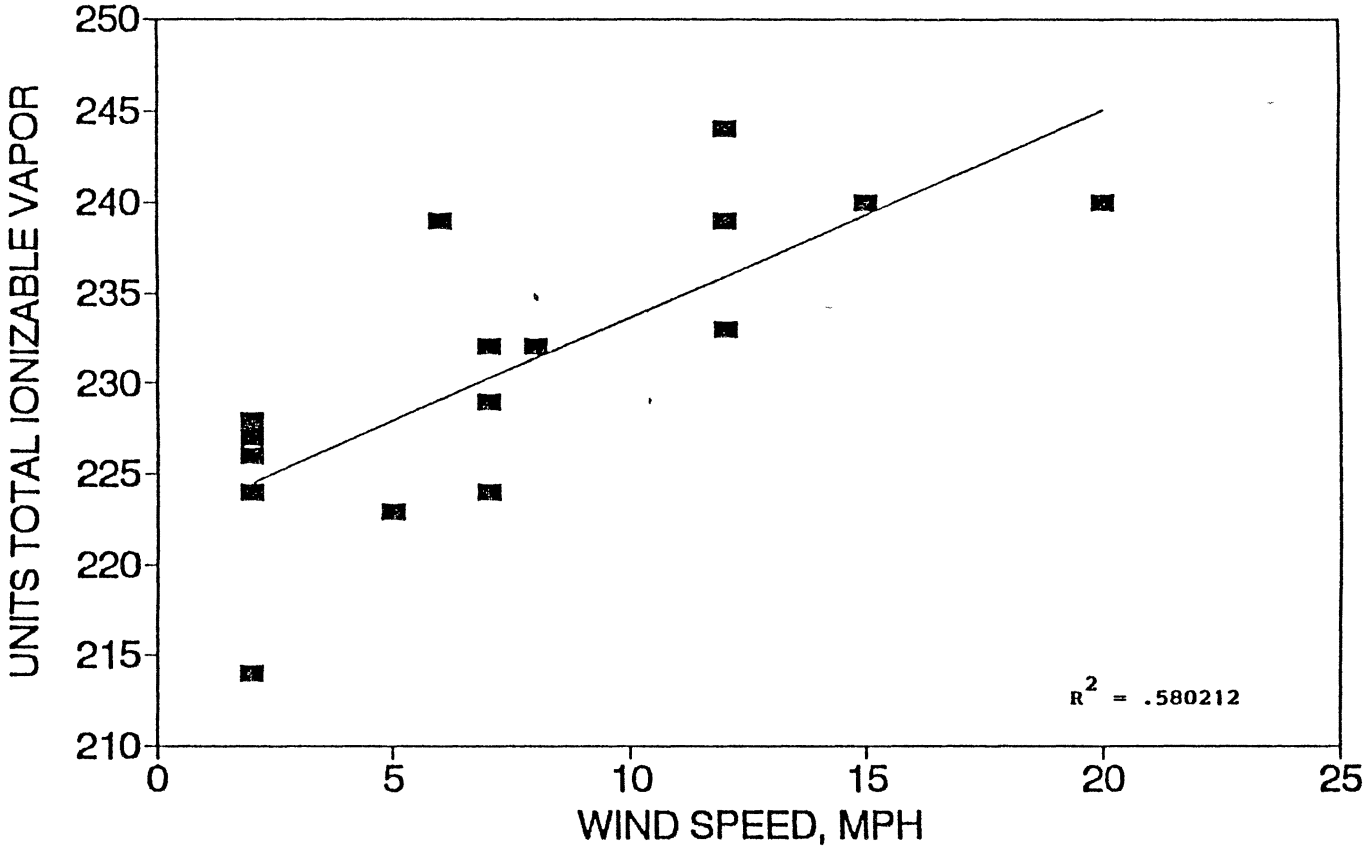


Figure 114. Scatter plot of TIV during diurnal study vs wind speed for SVP2

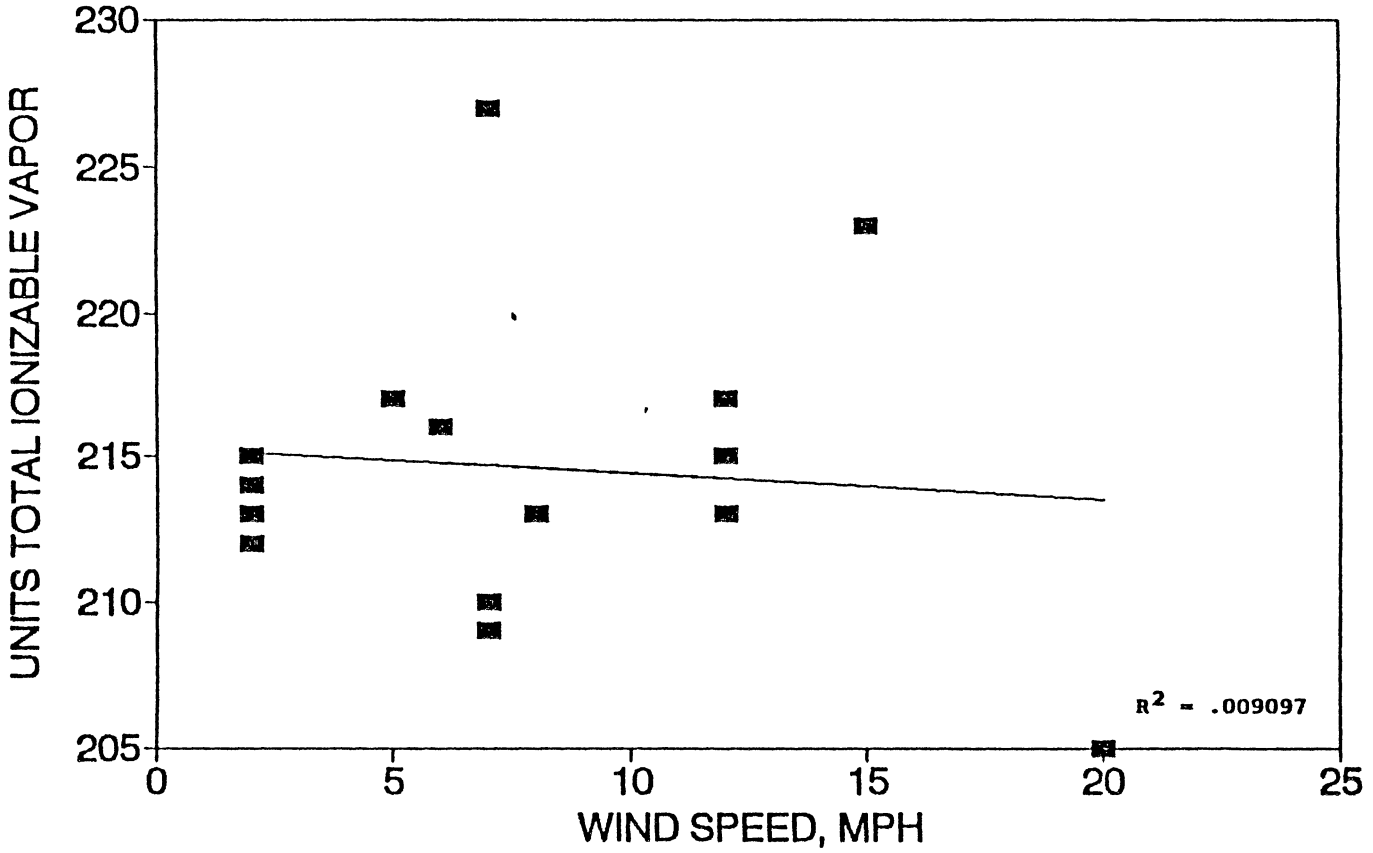


Figure 115. Scatter Plot of TIV during Diurnal Study vs relative humidity for SVP4

effect in the most permeable soils; thus SVP2 would be expected to display the most pronounced effect, as it apparently has. Wind speed did vary very nearly in parallel with temperature during the diurnal study, however, and again there may be collinear effects causing this apparent correlation.

Soil Moisture Effects

Increasing the percentage of moisture in soil interstices from zero to saturation is expected to cause first an increase in organic vapor concentration as water displaces adsorbed organics from soil minerals. As the soil vapor humidity approaches saturation, adsorption to soil minerals should have a relatively insignificant effect. Increasing soil water saturation from this point should then decrease soil organic vapor concentration as some organic constituents become dissolved in soil water and as water begins to fill pore spaces, inhibiting vapor movement. At full water saturation (field capacity) any vapor phase left in the soil would be encapsulated by water-filled pores, no vapor movement should occur, and organic vapor concentration would in effect be impossible to measure.

Soil moisture content was measured by dessication of soil samples collected, as described in Chapter IV. The resultant soil moisture percentages were plotted against TIV concentration for each sample point to create Figures

116 through 121. None of these plots show a linear relationship between soil moisture content and soil vapor concentration; R2 values for these linear regression calculations were all very low, the highest being .238. Research has shown that the rate of vapor diffusion through soils is related to moisture content, as discussed in the literature review section of Chapter I. The measured moisture content of the soils at this site varied from 11.8% to 19.1% during the course of this study; apparently this was not enough variation in moisture content to have a significant effect on vapor concentration at the sampling depth. One possible exception was recorded at sample point 4 on February 8, 1991: the moisture content was measured at 19.1%, and the TIV measured was the lowest measured in the core hole samples at that site; however 3 lower concentrations were measured in the soil vapor port at this site at lower soil water percentages. Another important effect of soil moisture was noted on June 14, 1991. After rainfall of 0.18 inches occurred during the previous night, an attempt was made to collect vapor samples from the vapor ports; both vapor ports 1 and 2 filled with water when the vapor sample pump was turned on. However the soil samples collected on this day did not have inordinately high water contents, ranging from 12.6 to 15.8 percent water by weight. Apparently the suction created by the sampling pump was enough to overcome the matric potential of the

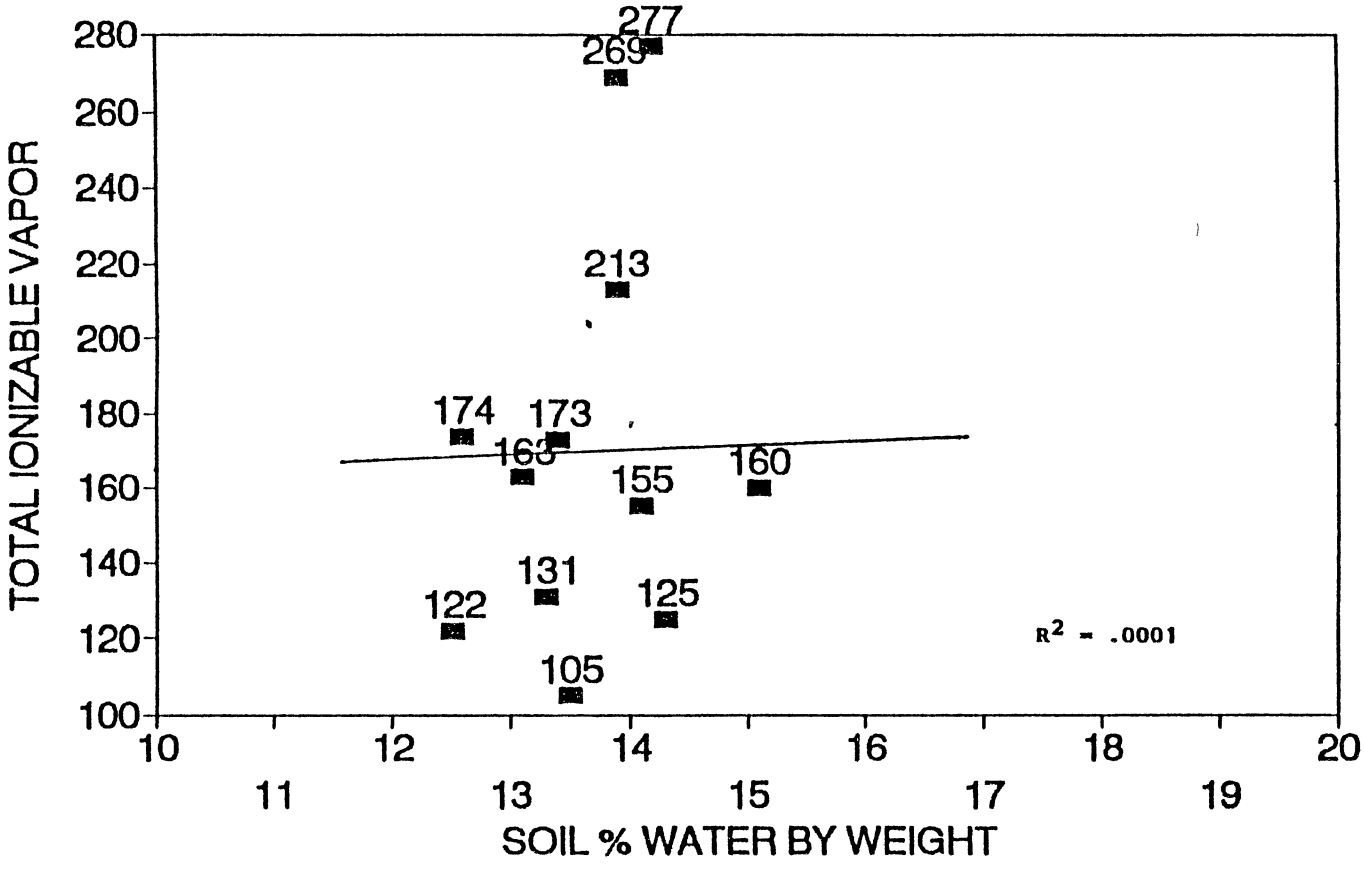


Figure 116. Scatter plot of TIV vs soil moisture in core holes at sample point 1, with regression line

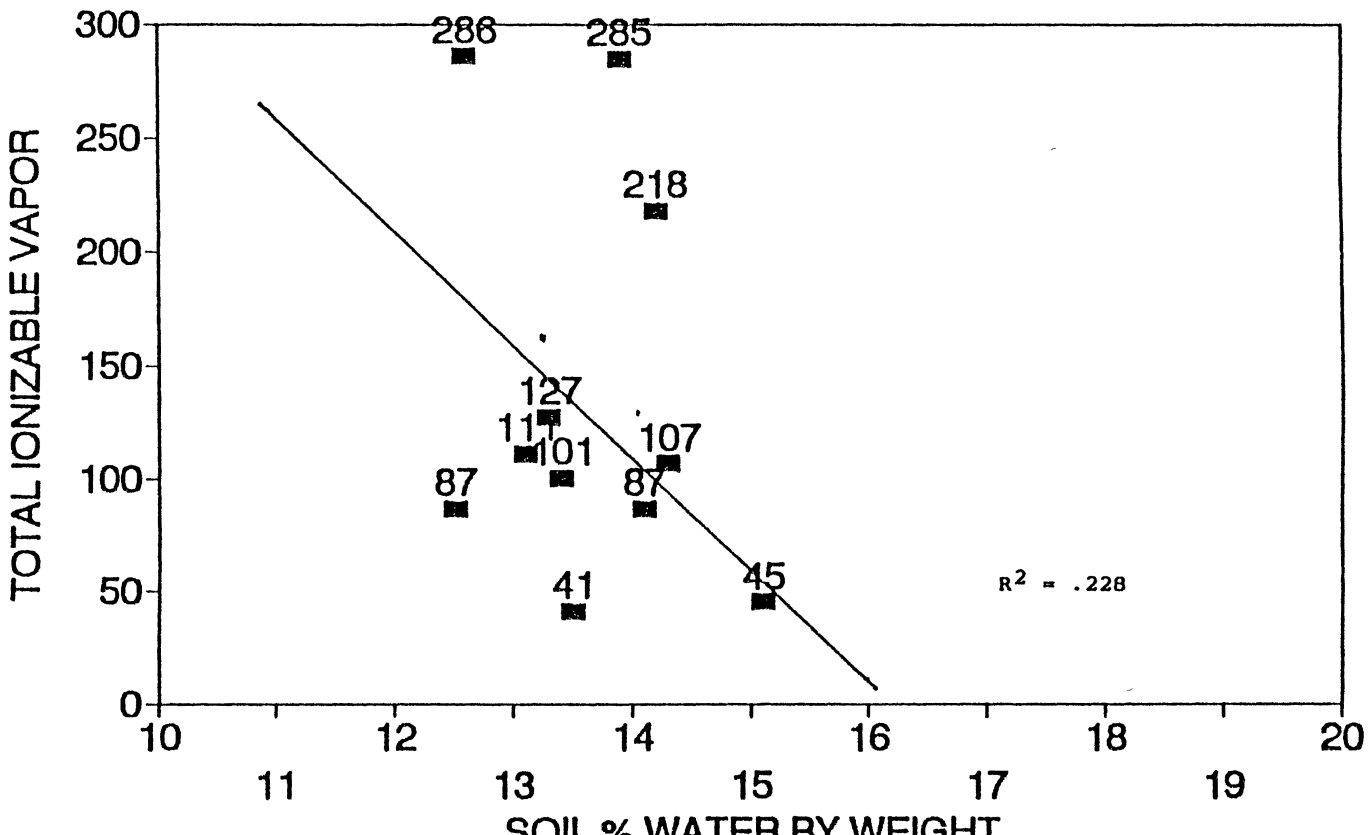


Figure 117. Scatter plot of TIV vs soil moisture in soil vapor port 1, with regression line

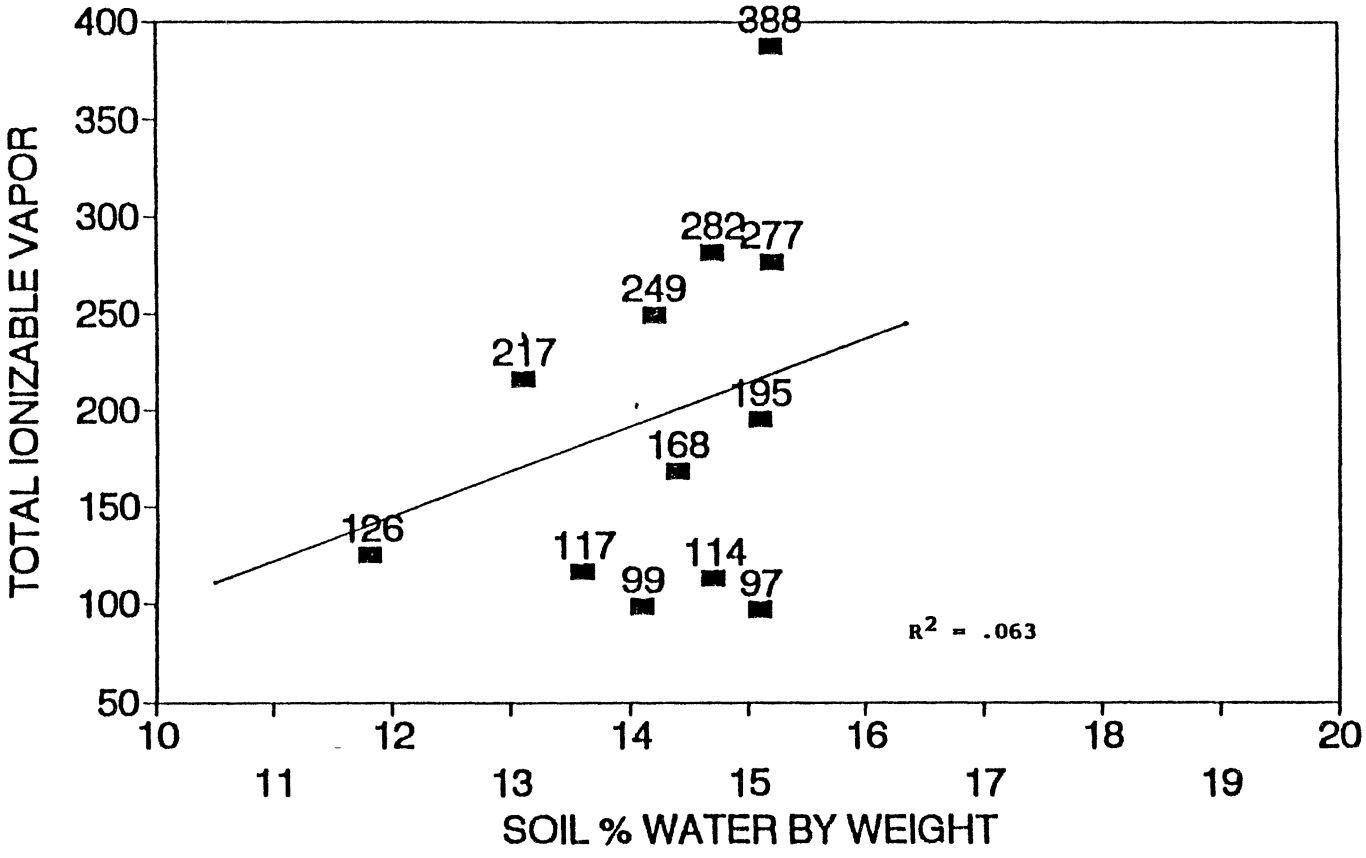


Figure 118. Scatter plot of TIV vs soil moisture in core holes at sample point 2, with regression line

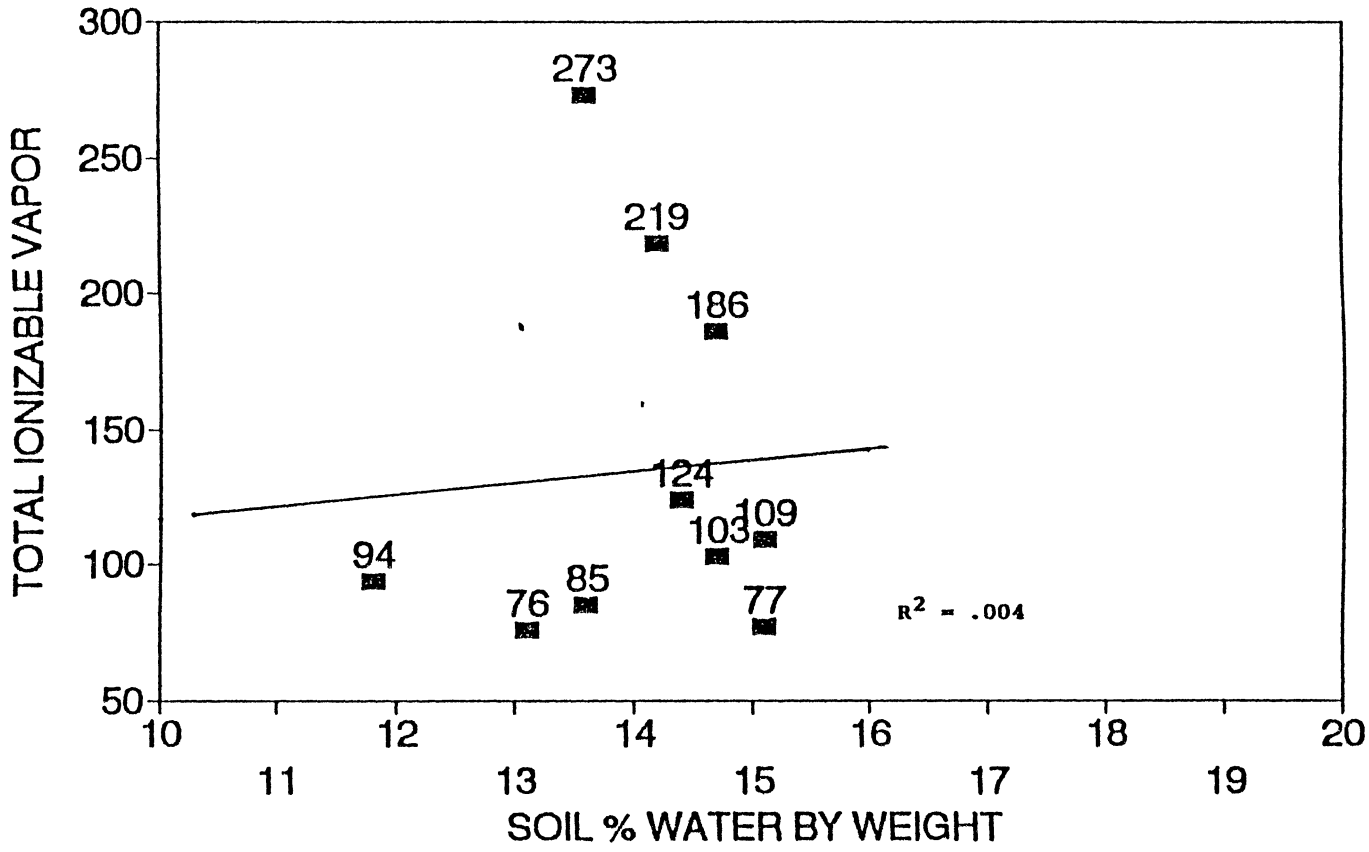


Figure 119. Scatter plot of TIV vs soil moisture in soil vapor port 2, with regression line

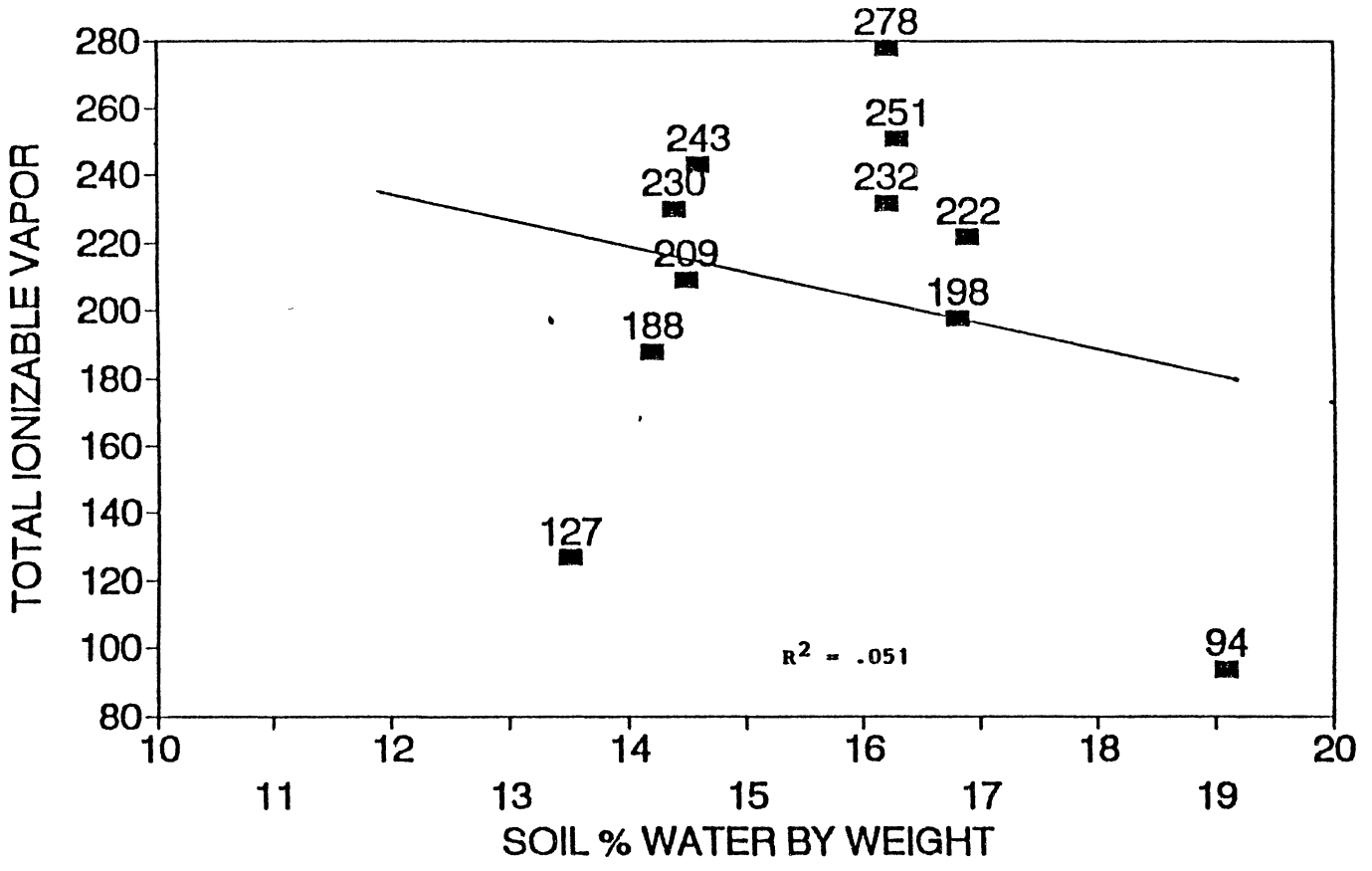


Figure 120. Scatter plot of TIV vs soil moisture in core holes at sample point 4, with regression line

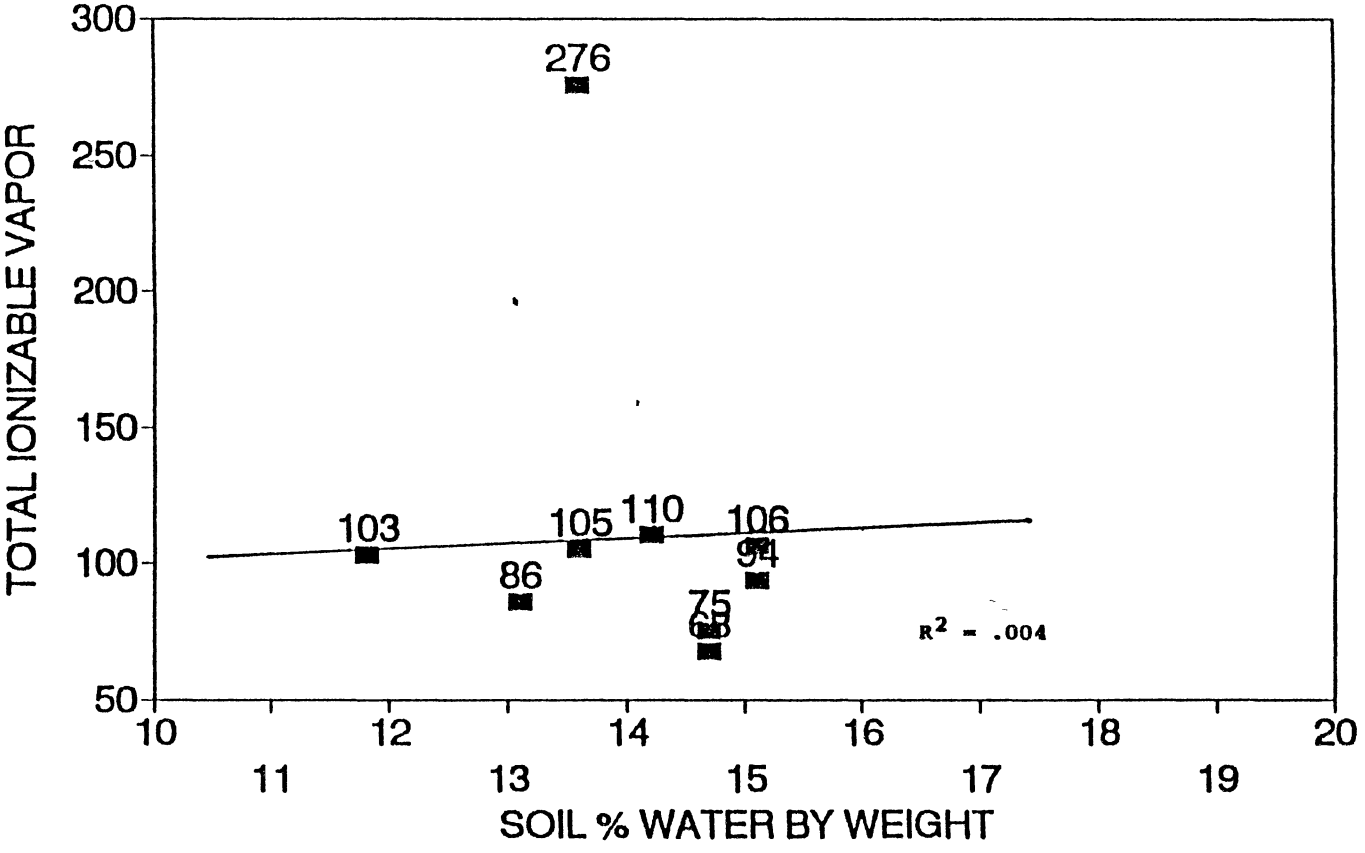


Figure 121. Scatter plot of TIV vs soil moisture in soil vapor port 4, with regression line

soil and fill the tubing of the soil vapor ports, even though the soil was not completely saturated. The soil at these two sampling locations apparently drains rapidly enough that it does not remain saturated for long after a rainfall. Thus the soil water content at this site does not have a major effect on the organic vapor concentration, as it remains close to field capacity most of the time; however shortly after a rainfall the increased water content will prevent the collection of a vapor sample through a probe or soil vapor port.

Depth to Fluid Effects

As discussed in Chapter 1 (and illustrated by Figure 1, page 16), the distance from the source material has been demonstrated to have an essentially linear relationship with organic vapor concentration in dry, isotropic soils (Kerfoot and Barrows, 1986). Thus with greater depth to fluid, lower volatile organic vapor concentrations are expected. Variations in soil type and moisture content would be expected to affect the gradient or perhaps skew the correlation from a straight line; the depth-concentration relationship should remain relatively clear, however.

Depth to fluid was measured for each sample point at each sample event during this study. The fluid level was descending for approximately the first three months of the study; with the advent of increased rainfall in May, the

water table began to rise, and continued to do so until the end of the study in late June. The soil vapor concentrations measured during this period in general rose continuously higher (with the exception of SVP3, which fell to zero and was abandoned). The fluctuation in depth to fluid was expected to have a strong influence on the concentration; however as shown by Figures 122 through 127, which illustrate the linear regressions for depth to fluid and TIV at all sample point, the expected correlation is not apparent. The data sets for all but the core hole samples at point 2 show a negative correlation, as expected; however the R2 values are very low, with the exception of the vapor port samples in SVP4, for which R2 is .679. There appears to be a grouping of higher concentrations at the lowest depth to fluid, and the remainder of the data seems to show an increase in concentration with increased depth to fluid. Upon closer examination of the data, it is apparent that these trends reflect merely the general trend of increasing vapor concentration with time as the study progressed.

Possible reasons for the poor correlation between depth to fluid may be that the sampling depth was too close to fluid level, and the changes in concentration due to fluid level fluctuation were too small to observe. It is also possible that because of the historically high fluid levels in the area, the hydrocarbons adsorbed to the soil

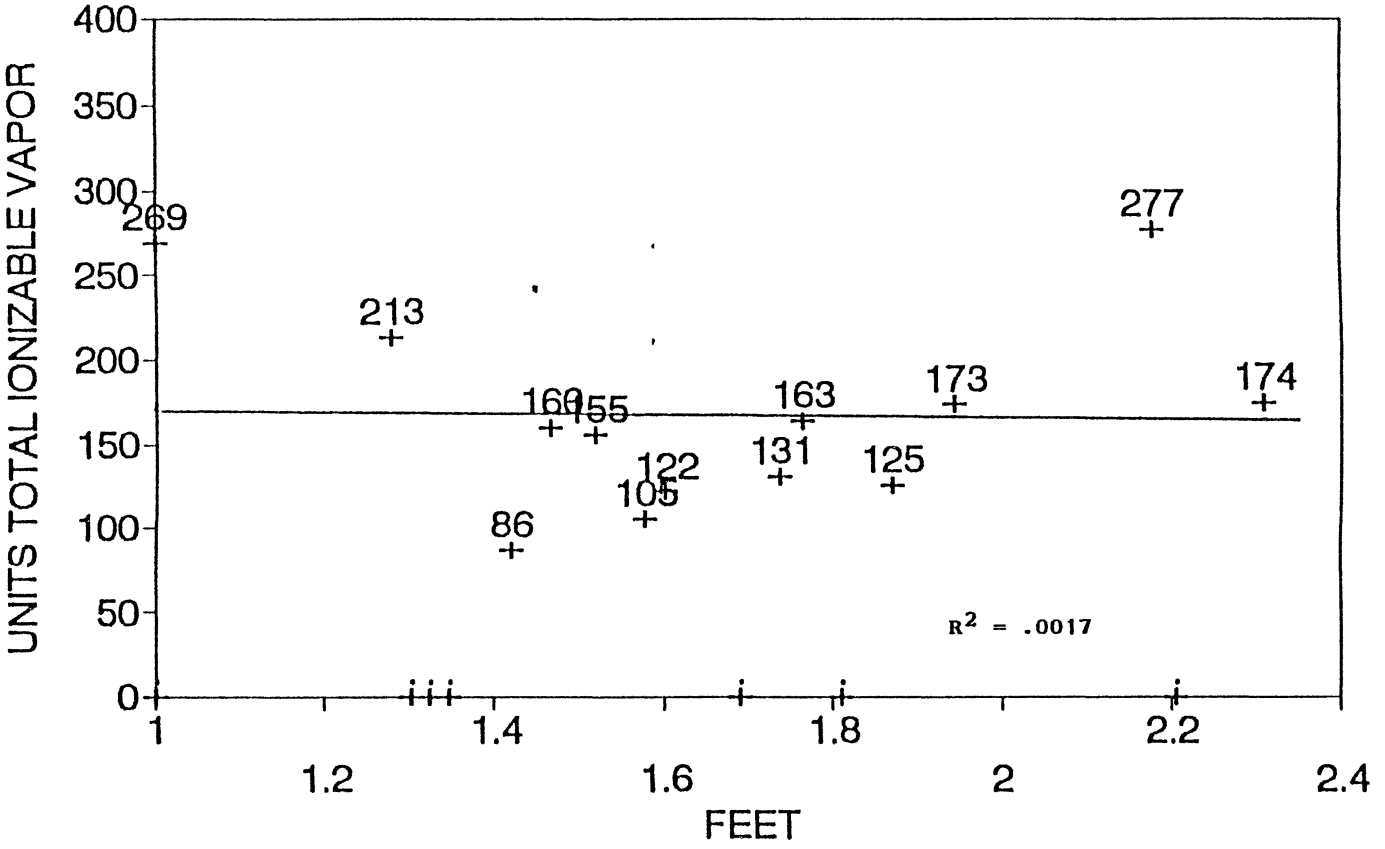


Figure 122. Scatter plot of TIV vs depth to fluid in core holes at sample point 1, with regression line

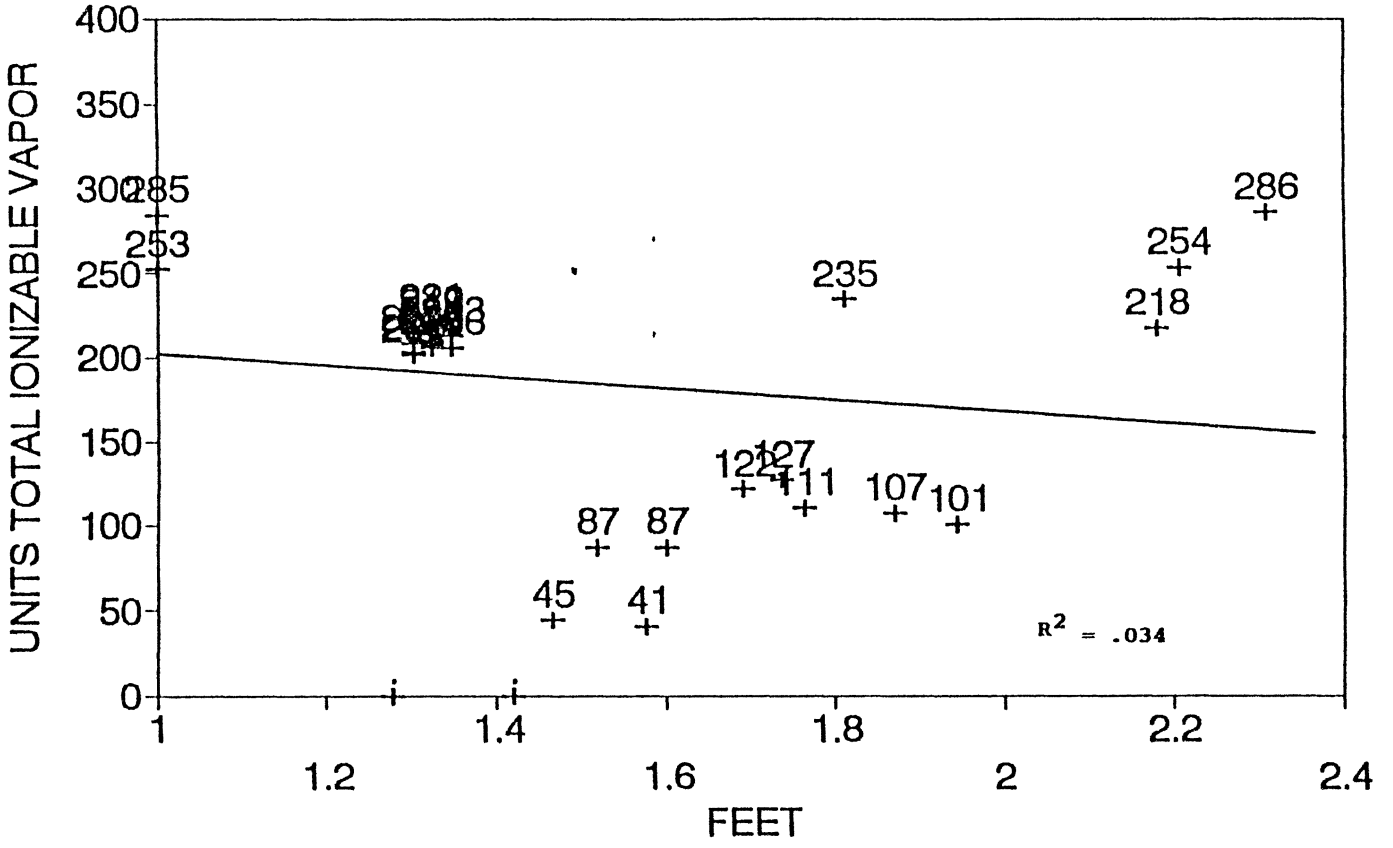


Figure 123. Scatter plot of TIV vs depth to fluid in soil vapor port 1, with regression line

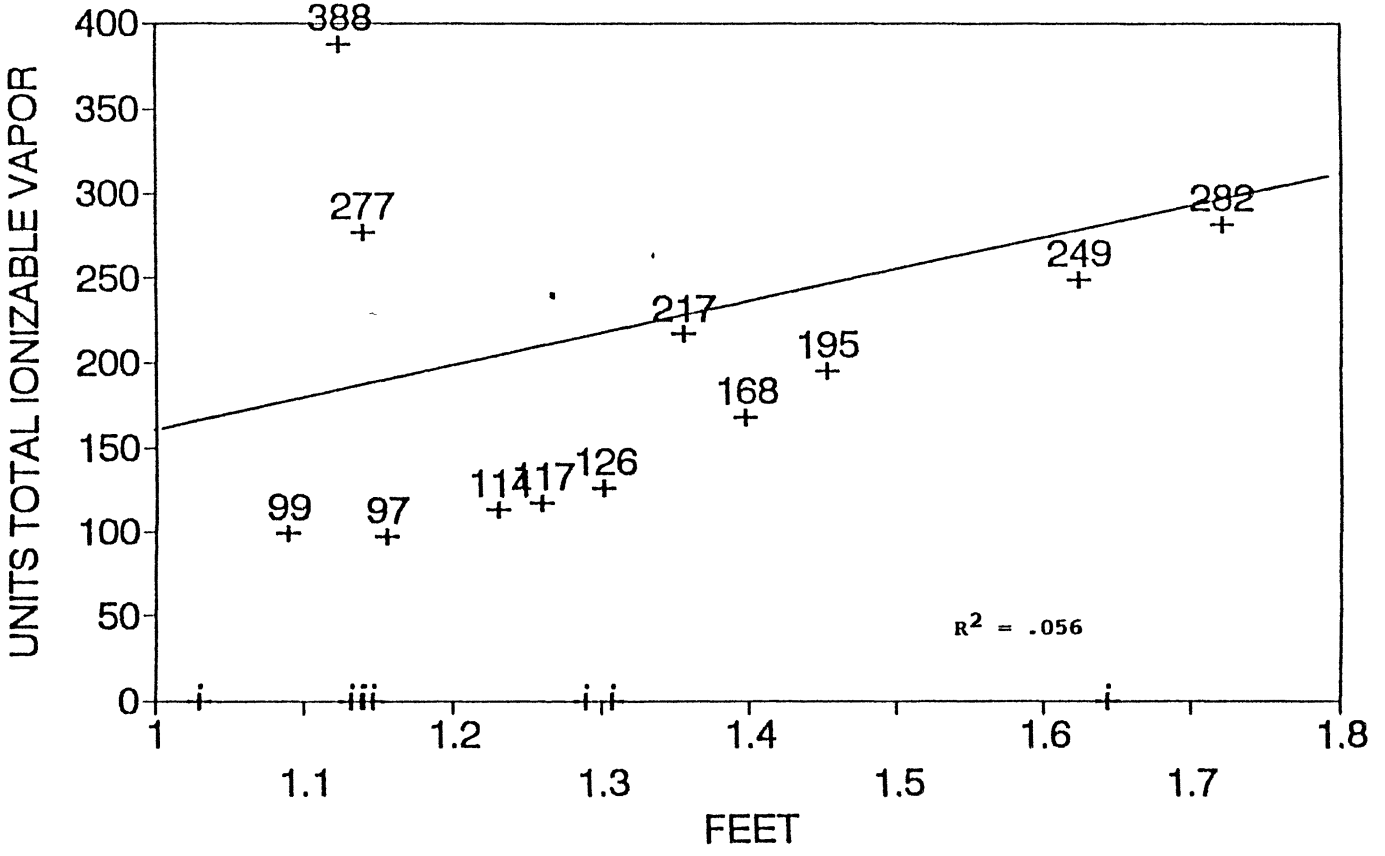


Figure 124. Scatter plot of TIV vs depth to fluid in core holes at sample point 2, with regression line

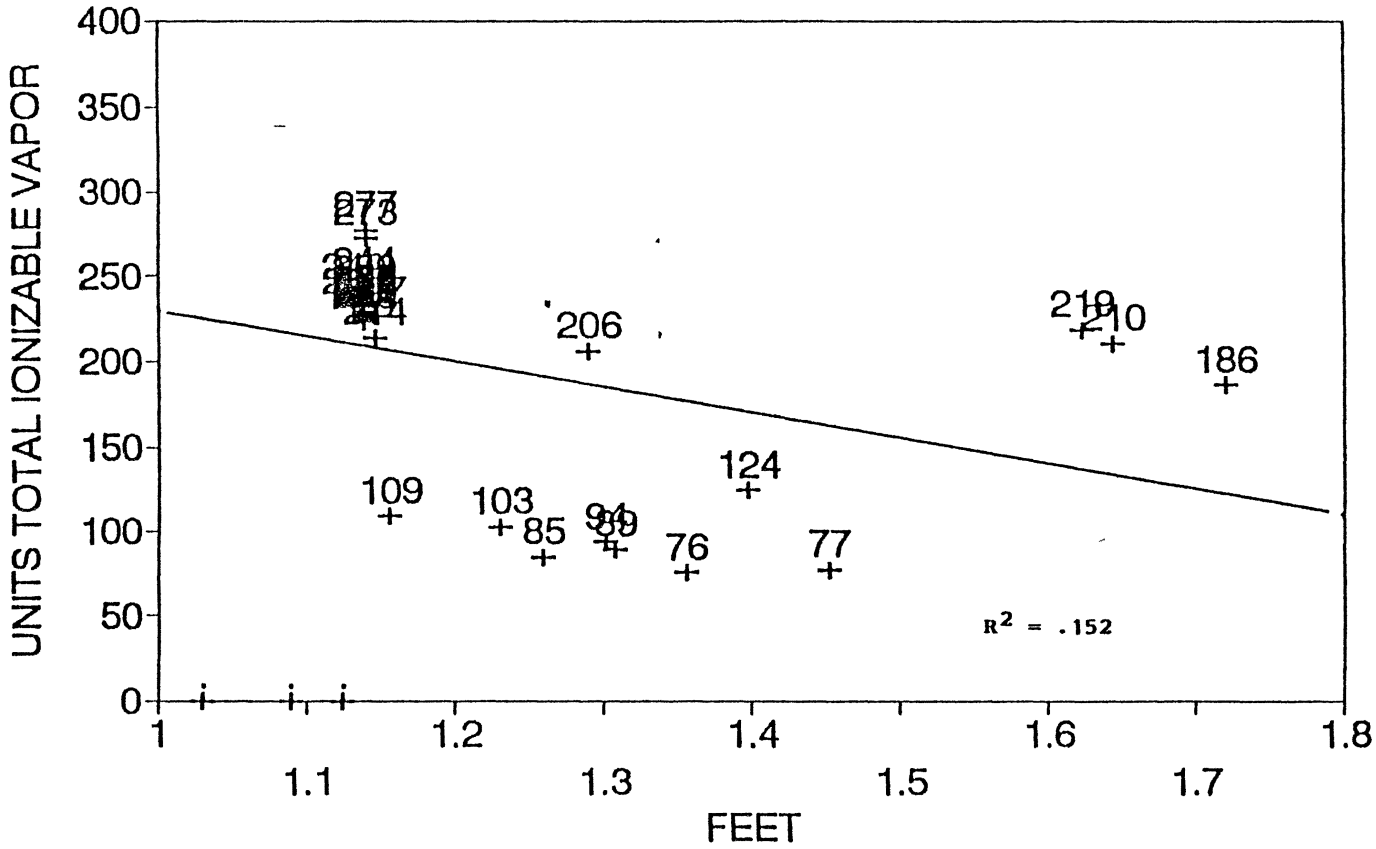


Figure 125. Scatter plot of TIV vs depth to fluid in soil vapor port 2, with regression line

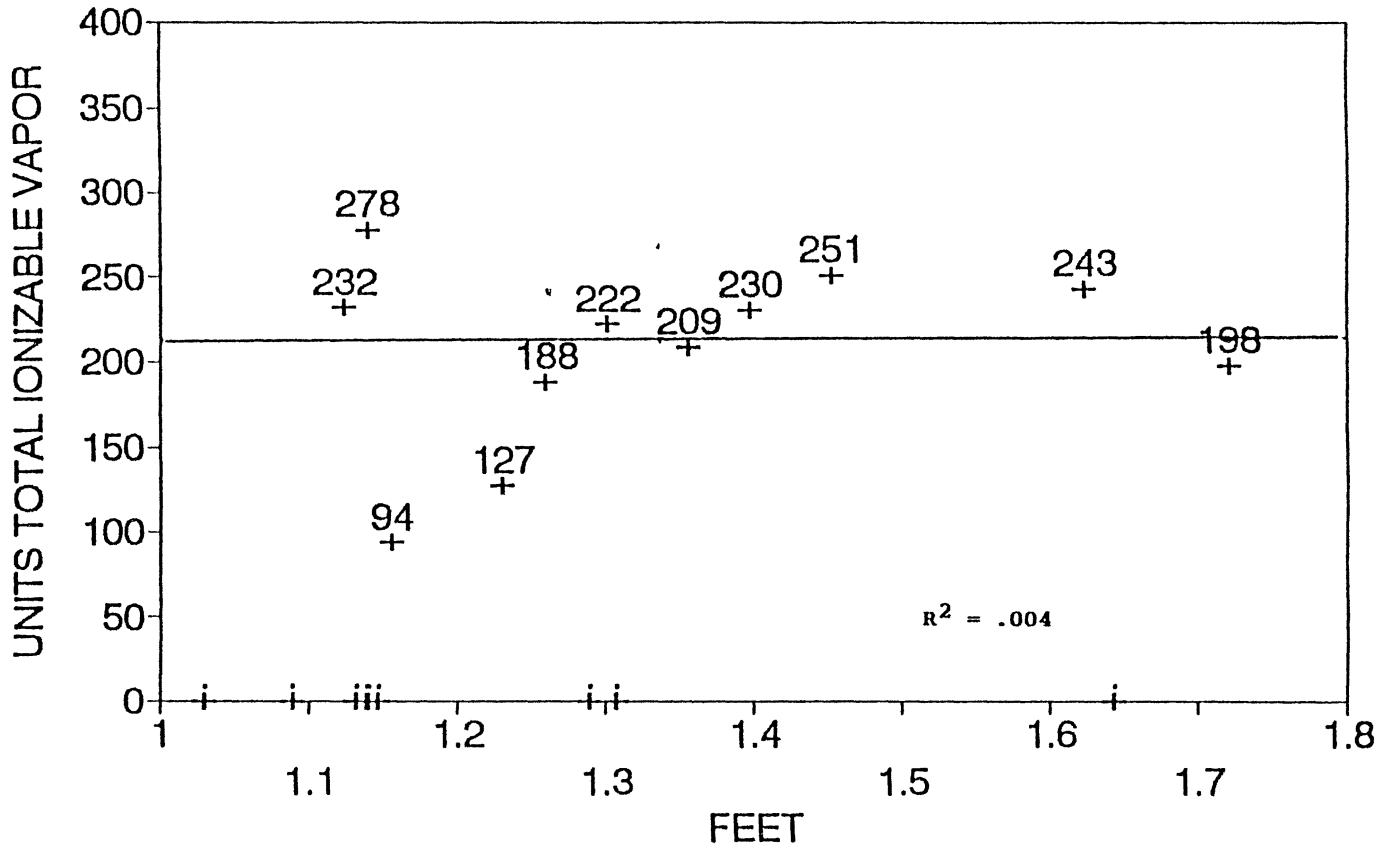


Figure 126. Scatter plot of TIV vs depth to fluid in core holes at sample point 4, with regression line

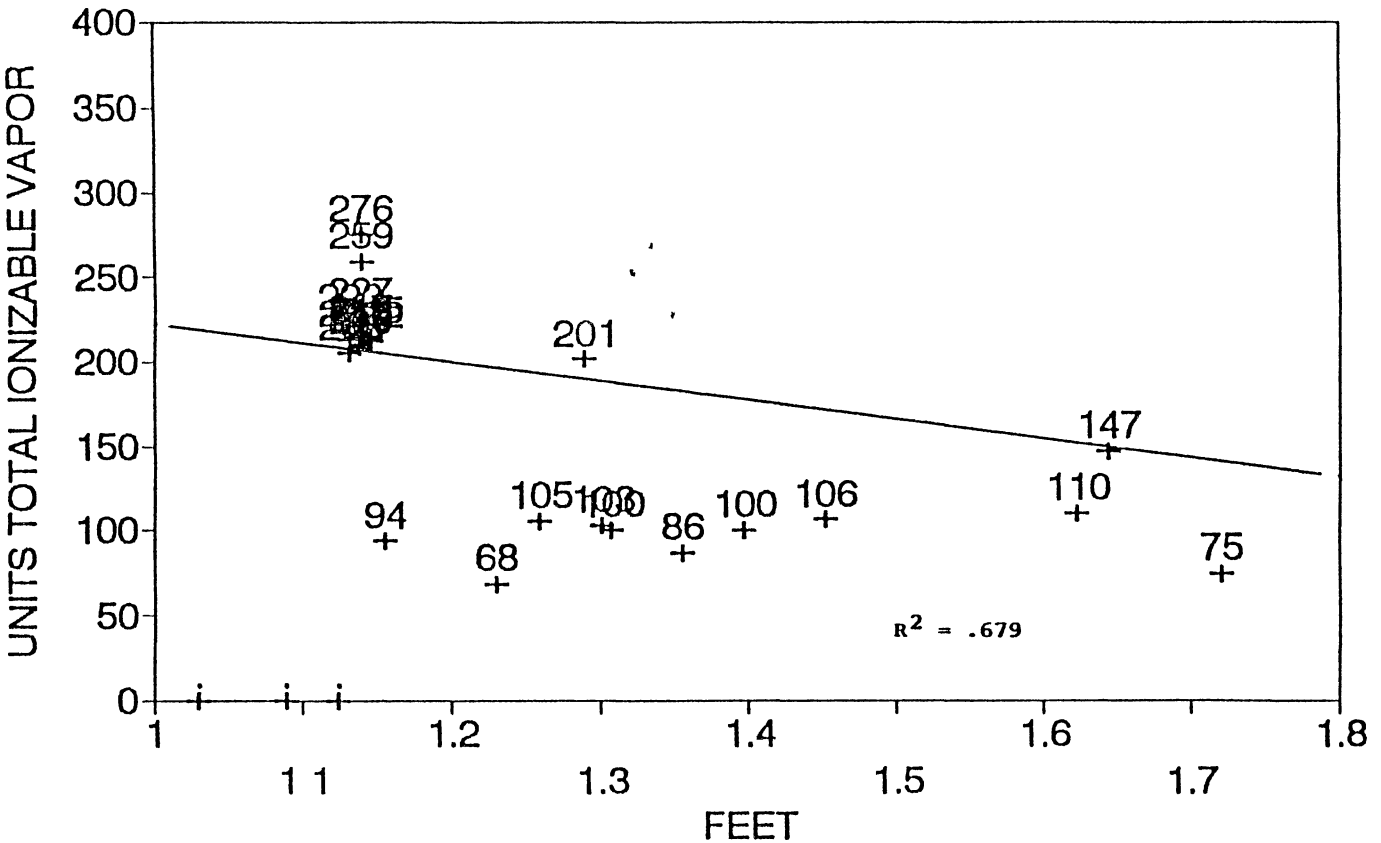


Figure 127. Scatter plot of TIV vs depth to fluid in soil vapor port 4, with regression line

are the primary source for the measured volatile organic vapors; thus the depth to fluid would have little effect.

Soil Temperature Effects

Perhaps the greatest effect on measured soil organic vapor concentration due to temperature would occur when soil temperature fell below freezing. Moisture in the soil would crystallize and expand in volume, which could seal off soil pores, preventing flow of soil vapors entirely (of course this effect would only occur when soil moisture content was high enough to begin with). Thus a frozen moist soil would resemble a fully water-saturated soil insofar as organic vapor measurement. Layers of frozen soils overlying volatile organic-contaminated ground water will act to trap the vapor, creating a much higher gradient below the frozen layer, much like a clay lens would, as illustrated by Figure 2 (page 17). (No frozen soils were encountered in this study). After the soil temperature rises above the freezing point, further increase in soil temperature would be expected to strongly increase soil organic vapor concentration by increasing volatilization of the liquid phase hydrocarbon and increasing the rate of diffusion.

As shown by Figures 128 through 133, soil temperature shows a distinct positive correlation with soil organic vapor concentration in the data from every sample point. With the exception of the core hole data at point 4, every

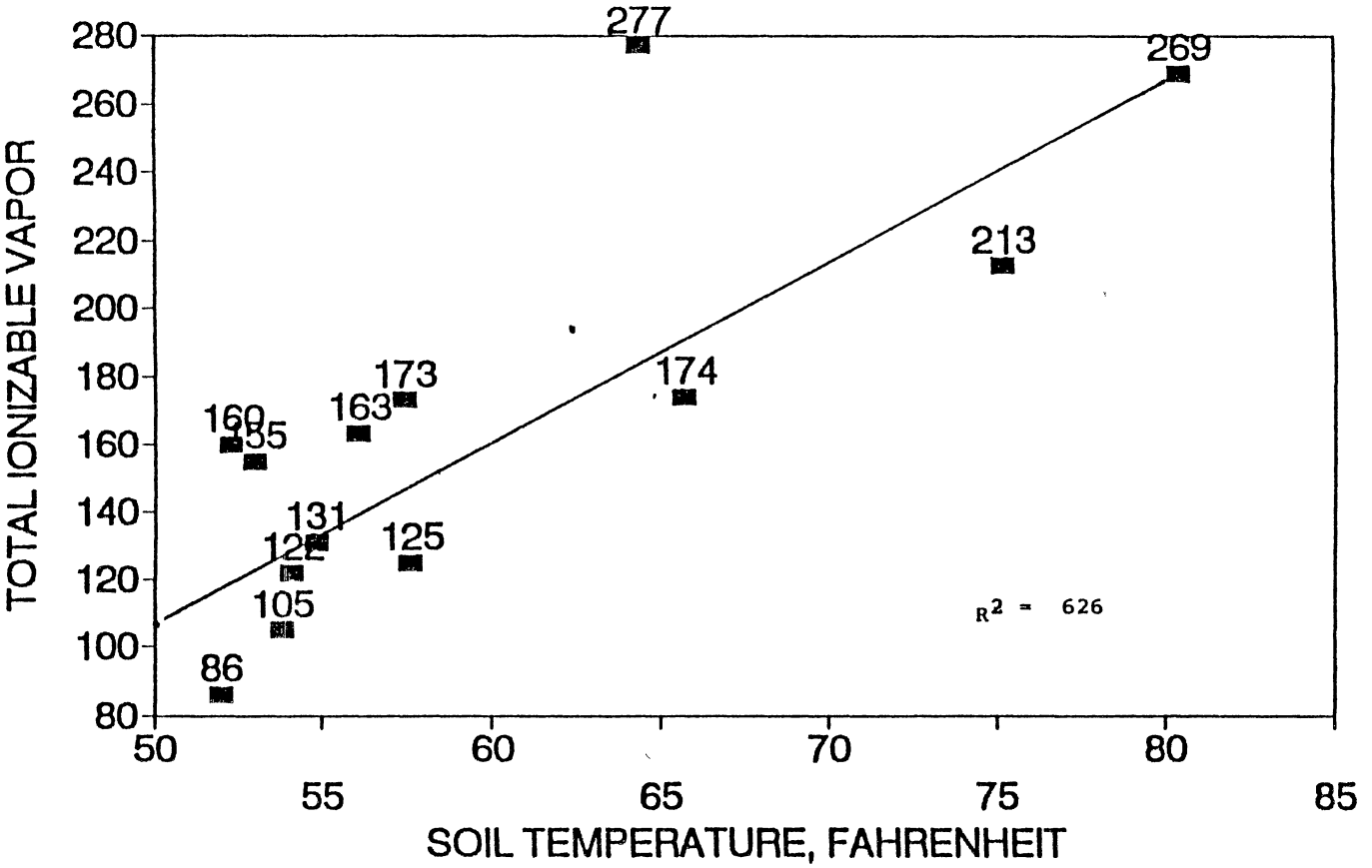


Figure 128. Scatter plot of TIV vs soil temperature in core holes at sample point 1, with regression line

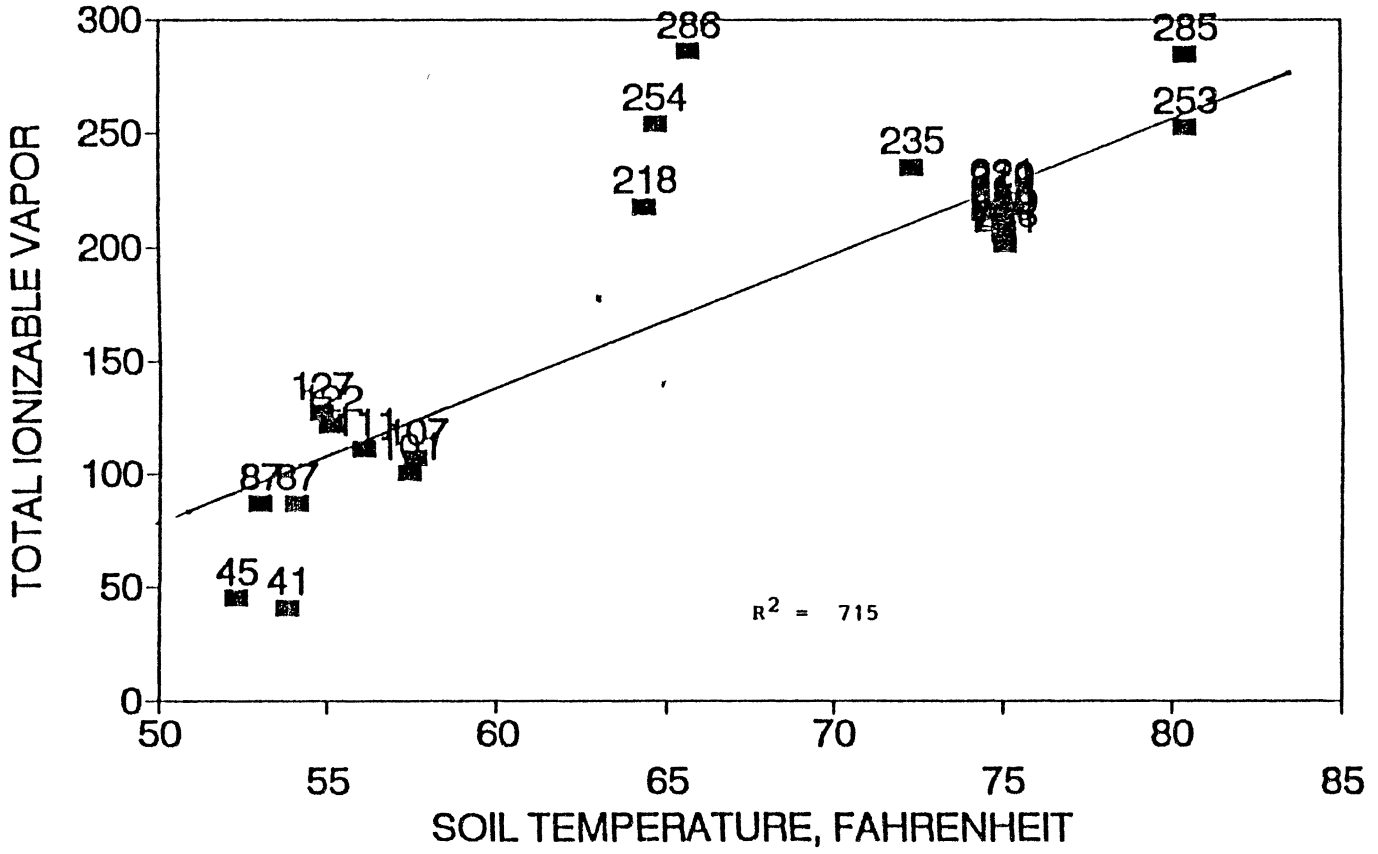


Figure 129. Scatter plot of TIV vs soil temperature in soil vapor port 1, with regression line

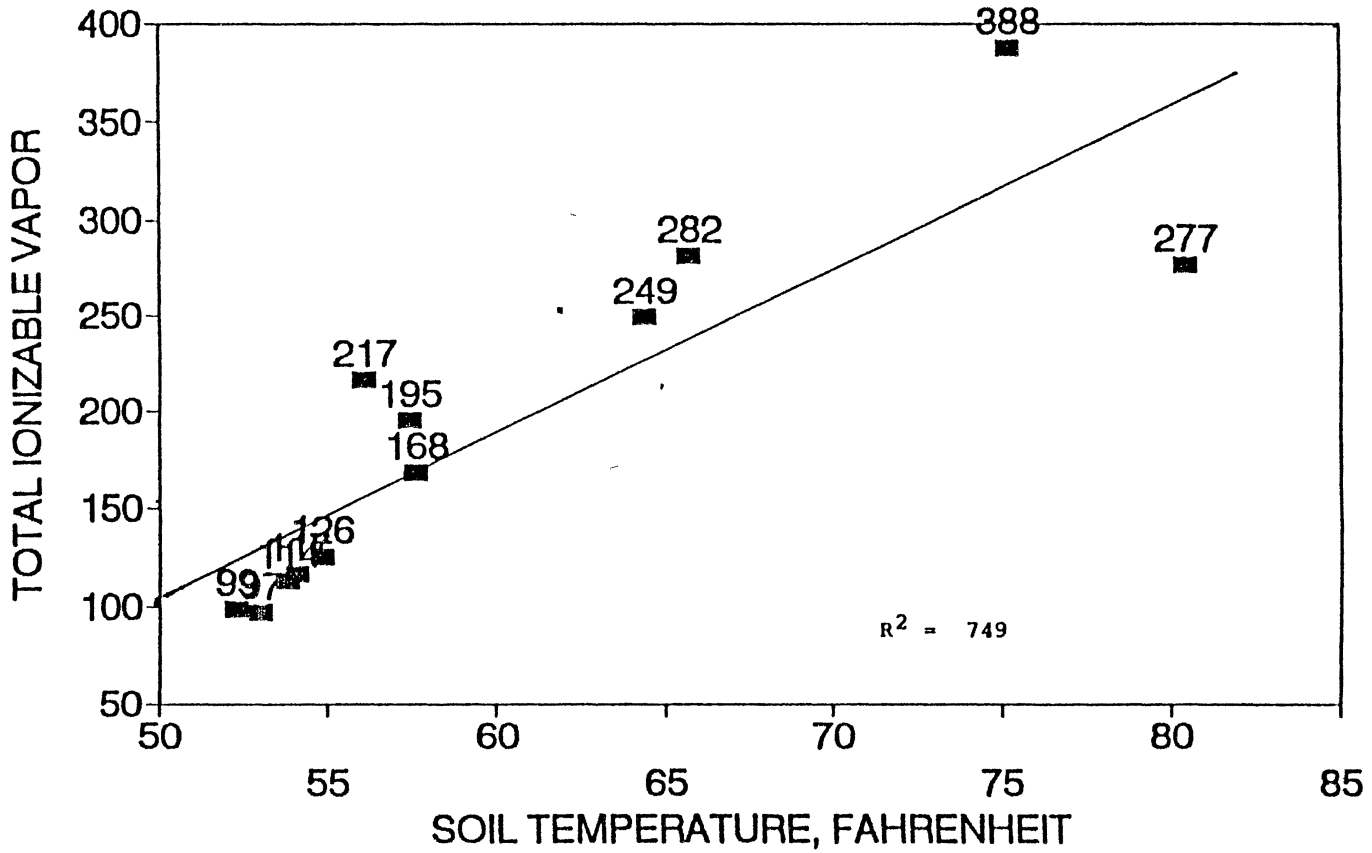


Figure 130. Scatter plot of TIV vs soil temperature in core holes at sample point 2, with regression line

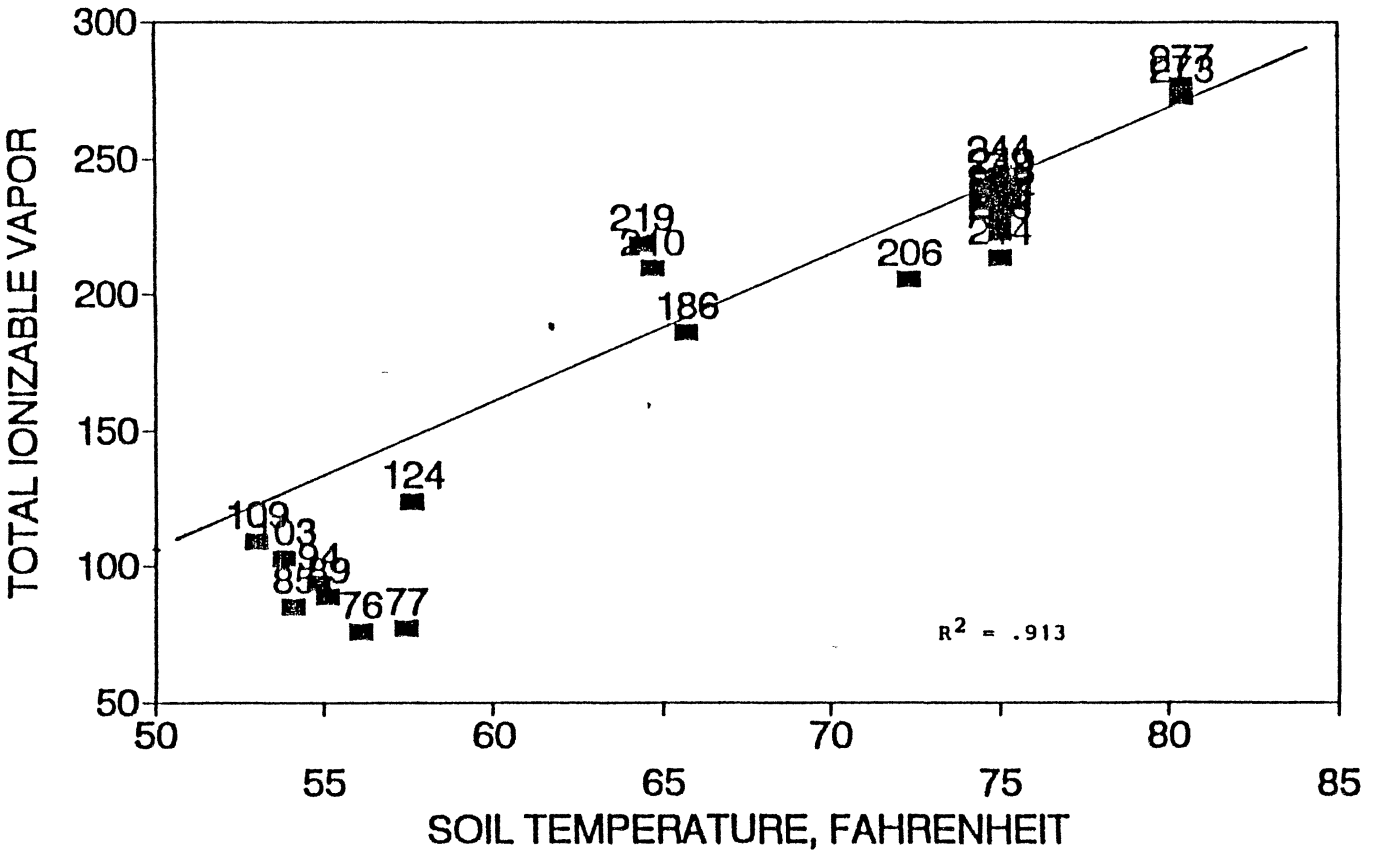


Figure 131. Scatter plot of TIV vs soil temperature in soil vapor port 2, with regression line

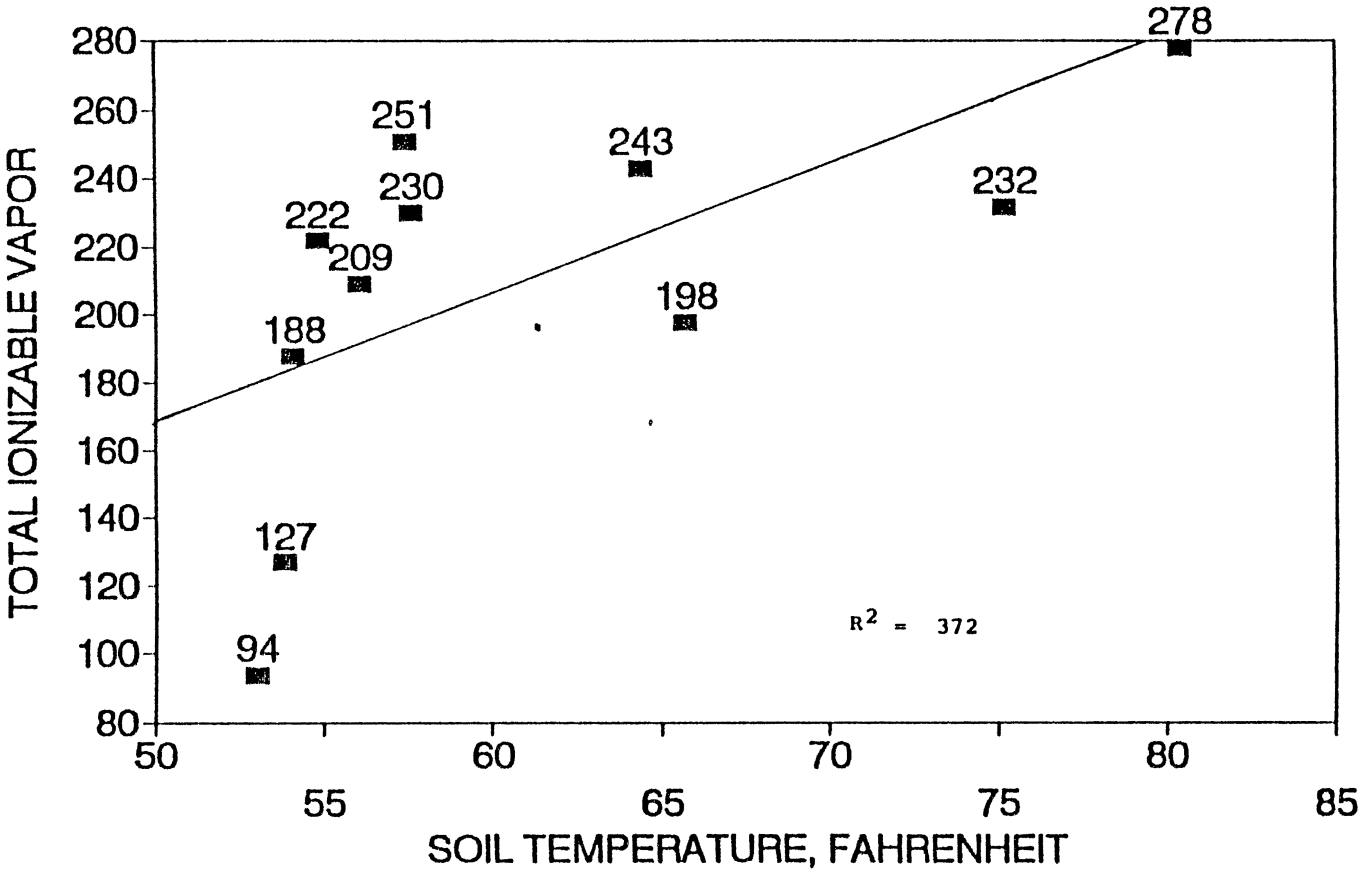


Figure 132. Scatter plot of TIV vs soil temperature in core holes at sample point 4, with regression line

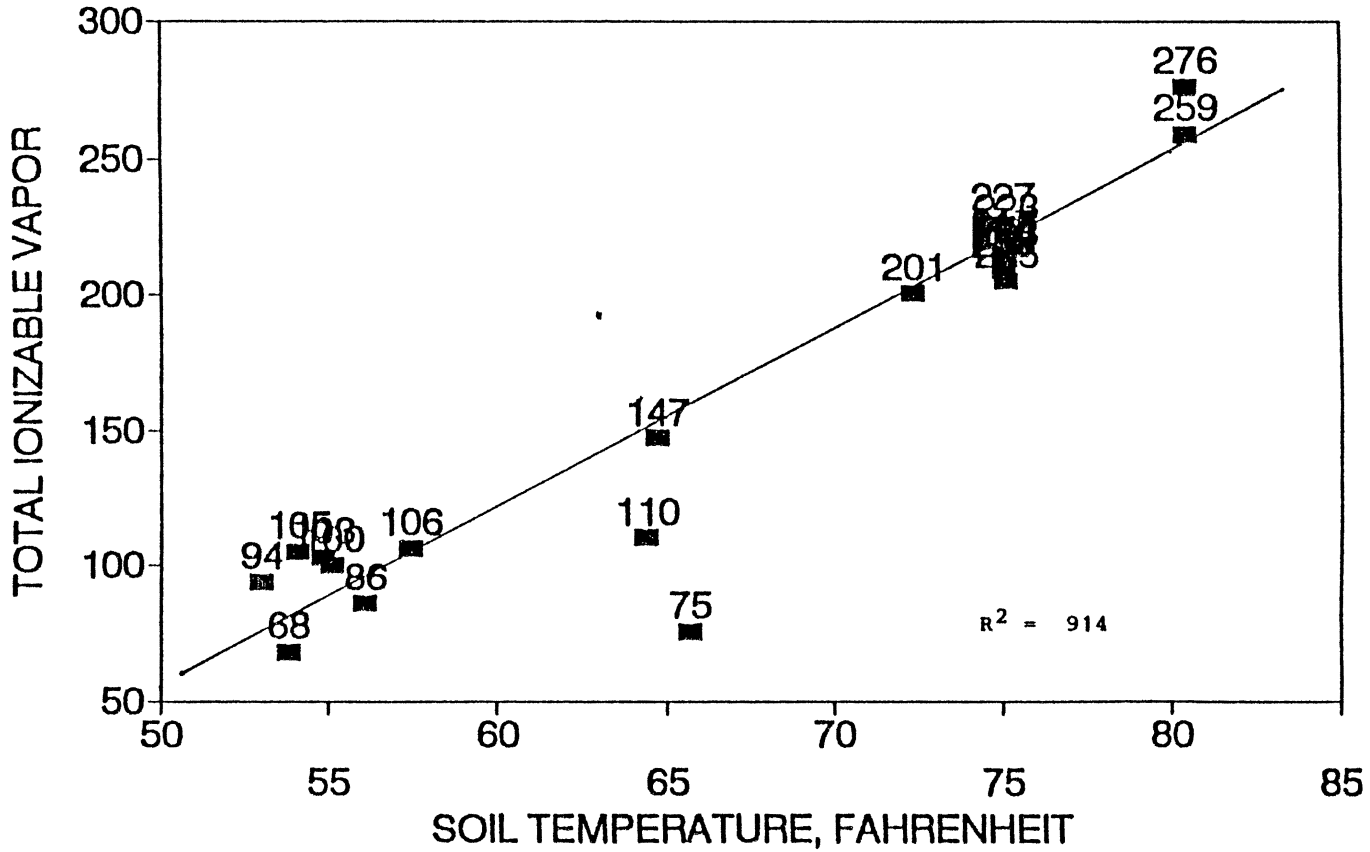


Figure 133. Scatter plot of TIV vs soil temperature in soil vapor port 4, with regression line

R2 value is from .6 to .9. This is by far the best fitting correlation of all the environmental variables, and there seems little doubt that soil temperature has a pronounced positive effect on the concentration of organic vapors in the soil at this site. Figures 134 through 136 illustrate this correlation; soil vapor concentration was predicted using the soil temperatures and linear regression coefficients and constants averaged from the core hole and vapor port data regressions. This predicted value for each sample date was then plotted with the actual data to illustrate how soil organic vapor concentration at a constant depth from surface changes with soil temperature. It is of particular interest to note that sample point 2, with more sandy soil, has a higher coefficient (7.5) than the clayey soils, which have very similar coefficients (5.35 for point 2 and 5.44 for sample point 4); thus soil organic vapor concentration apparently has a greater response to changing soil temperature in sandy soils than in clayey soils.

Multiple Regression Analyses and Interpretations

Multiple regression analyses were calculated for each sample point, both on the long-term data set and separately for the diurnal data. Multiple regression analysis uses matrix algebra to assign a coefficient for each independent

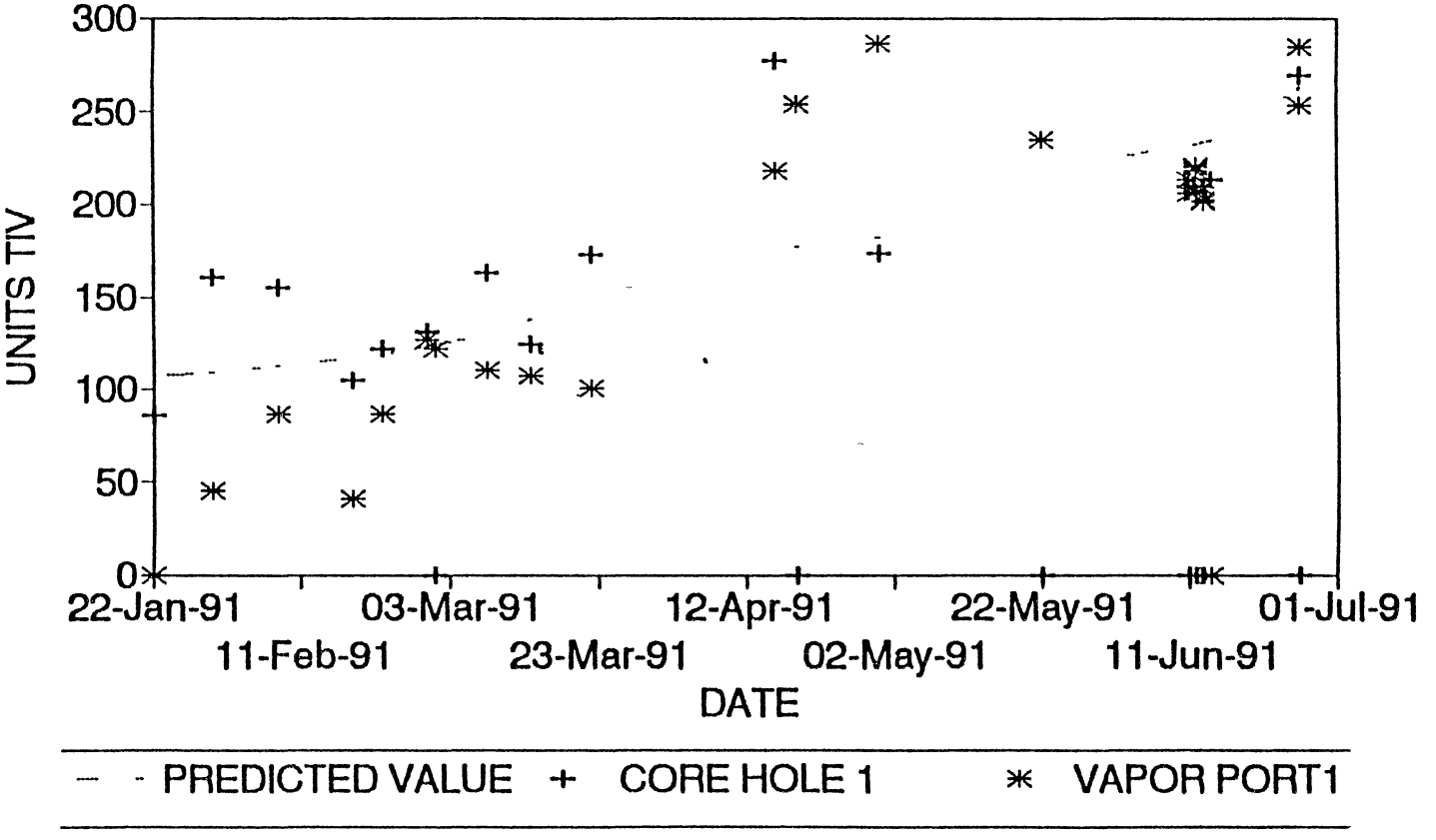


Figure 134. Plot of measured and predicted concentrations, as predicted by linear regression model for soil temperature using averaged coefficients for core hole and vapor port data, sample point 1

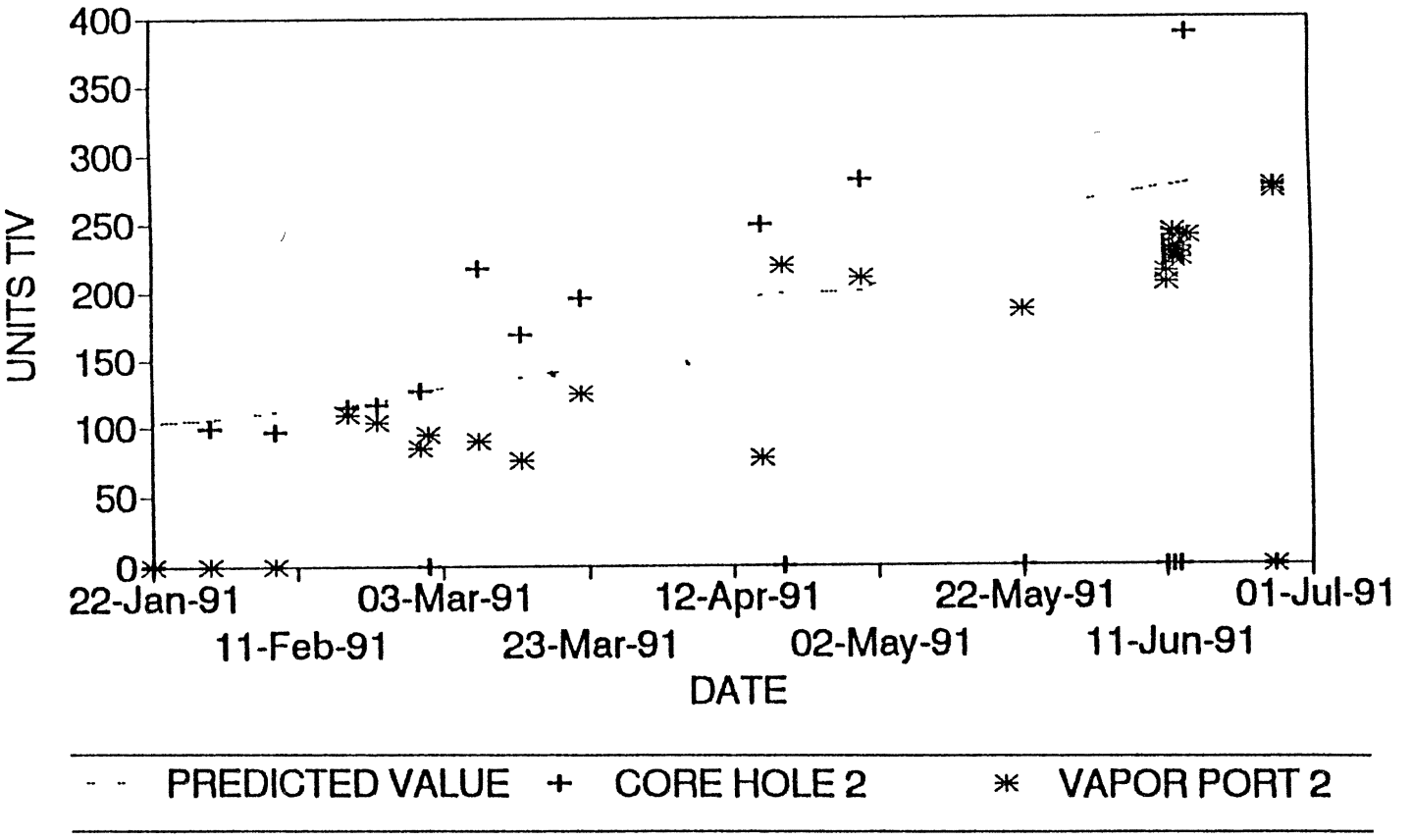


Figure 135. Plot of measured and predicted concentrations, as predicted by linear regression model for soil temperature using averaged coefficients for core hole and vapor port data, sample point 2

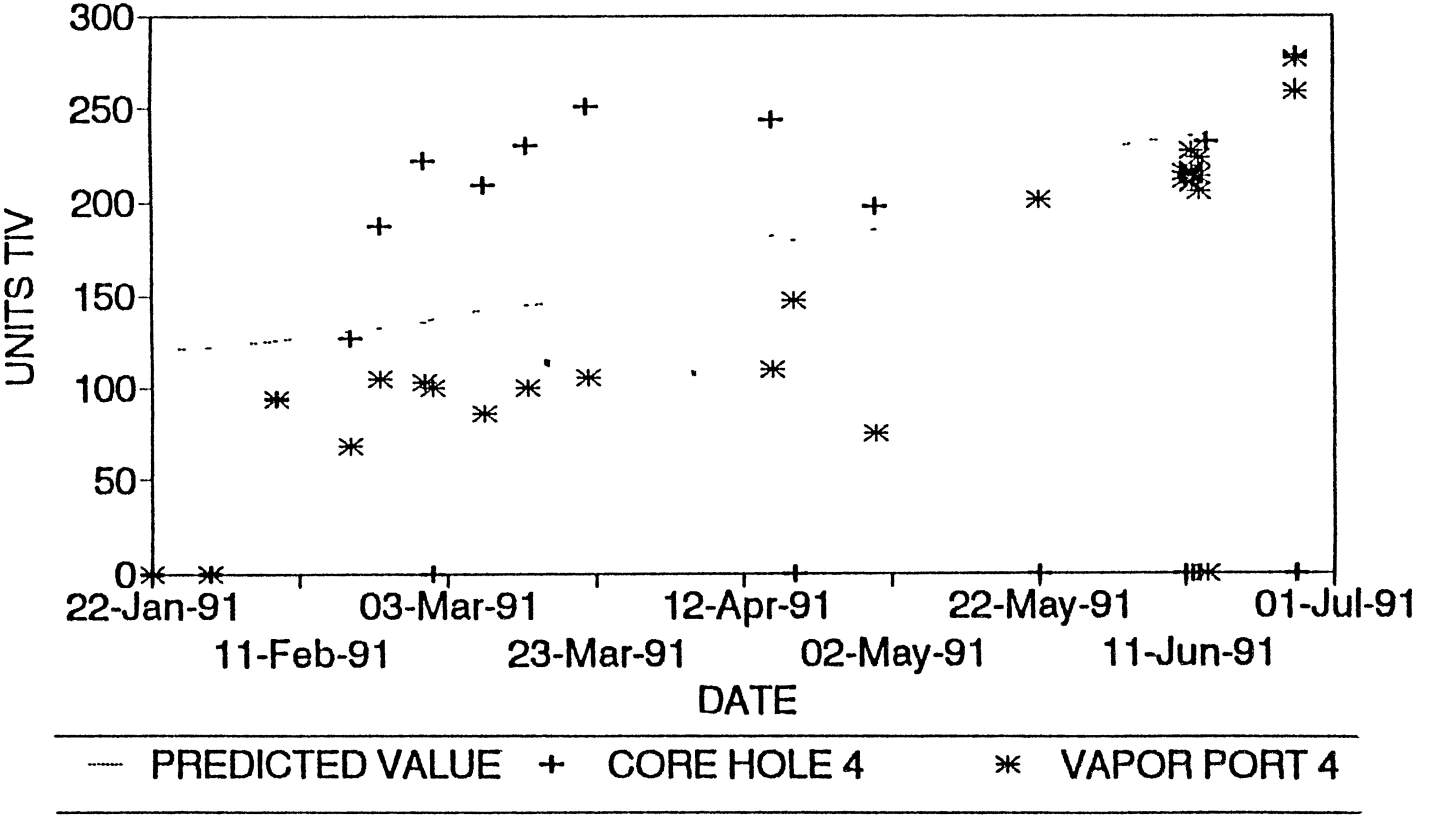


Figure 136. Plot of measured and predicted concentrations, as predicted by linear regression model for soil temperature using averaged coefficients for core hole and vapor port data, sample point 4

variable, and a constant. The resultant equation is of the form:

$$Y = A1X1 + A2X2 + A3X3 \ldots\ldots + c;$$

where A1 through A3 are the coefficients for each independent variable X, and c is the constant term. The SYSTAT program also calculates an R2 value, which expresses the "goodness of fit" of the dependant variable values predicted by the regression model to the actual data, as in linear regression.

The SYSTAT program also calculates the T statistic, which is the coefficient divided by the standard error for each variable. The T statistic is used to test hypotheses about the value of the coefficient. The T statistic is dependant on the number of observations made (n) minus the number of coefficients calculated (m), which equals the degrees of freedom (DF). The T statistic must be higher than a pre-determined value (obtained from a table of T statistics) to be considered valid at a given level of confidence. T statistics are listed by the percentage confidence level; that is, if the T statistic is found to be above the value listed at the 95% confidence level, it is considered proven with 95% confidence that the coefficient is not zero. The program also calculates condition indices, which are used for indications of collinearity in the model. Condition indices above 15 indicate collinearity problems; above 30 indicate serious collinearity problems, meaning that some variables are so

inter-related that their effects may not be satisfactorily separated.

Multiple Regression Results for Long-Term Data

All the independent variables measured were modeled by multiple regression. It should be noted that the variables measured in this study do not represent all the variables which may possibly affect the concentration of volatile organic vapors measured in soil vapor; therefore the results of the statistical analyses cannot be universally applied. The multiple regression analyses were conducted to determine the comparative effects of the measured variables only. The modeled variables generally fit well with the actual data, as shown by Table VIII; R2 values ranged from .851 to .981. As shown by Table VIII, the T statistics for many of the independent variable coefficients are not within acceptable confidence limits, and every multiple regression resulted in high condition indices. Thus while the multiple regression model for all independent variables did an excellent job of predicting the measured concentrations, it has not provided the "true" correlation coefficients for the independent variables.

As shown by Table VIII, the coefficients for the independent variables have not only widely variant absolute values, but opposite polarities for the different sets of modeled data. Thus the independent variables apparently

TABLE VIII

MULTIPLE REGRESSION CALCULATIONS RESULTS

CORE HOLE DATA, POINT 1

N: 12 MULTIPLE R: .936 MULTIPLE R2: .877

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	-5064.346	2094.813	-2.418	0.073	95%
TEMP	1.747	1.449	1.206	0.294	75%
RH	-0.916	1.250	-0.733	0.504	NA
BP	4.575	2.042	2.240	0.089	95%
WIND	1.736	1.207	1.438	0.224	NA
ST1	4.534	2.212	2.050	0.110	90%
SM1	18.093	13.607	1.330	0.254	75%
DTF1	-10.308	35.226	-0.293	0.784	NA

CONDITION INDICES >30

VAPOR PORT DATA, POINT 1

N: 11 MULTIPLE R: .983 MULTIPLE R2: .966

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	-3124.466	1975.435	-1.582	0.212	75%
TEMP	0.611	1.345	0.454	0.680	NA
RH	1.249	1.147	1.089	0.356	75%
BP	2.570	1.951	1.317	0.279	75%
WIND	0.386	1.108	0.349	0.750	NA
DTF1	86.995	32.767	2.655	0.077	95%
ST1	8.556	2.022	4.230	0.024	99%
SM1	-7.899	13.605	-0.581	0.602	NA

CONDITION INDICES >30

CORE HOLE DATA, POINT 2

N: 12 MULTIPLE R: .922 MULTIPLE R2: .851

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	1092.340	3820.558	0.286	0.789	NA
TEMP	0.259	2.779	0.093	0.930	NA
RH	-1.484	2.278	-0.651	0.550	NA
BP	-1.601	3.768	-0.425	0.693	NA
WIND	-0.538	2.160	-0.249	0.816	NA
DTF2	112.526	110.797	1.016	0.367	75%
ST2	8.708	3.883	2.243	0.088	95%
SM2	7.793	19.144	0.407	0.705	NA

CONDITION INDICES >30

TABLE VIII
(continued)

VAPOR PORT DATA, POINT 2

N: 10 MULTIPLE R: .979 MULTIPLE R2: .959

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	-1124.552	1996.277	-0.563	0.630	NA
TEMP	2.128	1.632	1.304	0.322	75%
RH	0.813	1.162	0.699	0.557	NA
BP	0.661	1.981	0.334	0.770	NA
WIND	-1.269	1.119	-1.135	0.374	75%
DTF2	60.038	62.024	0.968	0.435	NA
ST2	4.634	2.034	2.279	0.150	90%
SM2	4.960	10.435	0.475	0.681	NA

CONDITION INDICES >30

CORE HOLE DATA, POINT 4

N: 11 MULTIPLE R: .923 MULTIPLE R2: .852

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	350.693	2991.494	0.117	0.914	NA
TEMP	-3.221	2.149	-1.498	0.231	75%
RH	-0.432	1.428	-0.303	0.782	NA
BP	-0.281	3.043	-0.092	0.932	NA
WIND	2.816	1.668	1.688	0.190	75%
DTF4	4.676	40.970	0.114	0.916	NA
ST4	7.986	3.137	2.546	0.084	95%
SM4	-9.770	9.733	-1.004	0.389	75%

CONDITION INDICES >30

VAPOR PORT DATA, POINT 4

N: 10 MULTIPLE R: .990 MULTIPLE R2: .981

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	-1409.724	1415.203	-0.996	0.424	75%
TEMP	-0.549	1.021	-0.538	0.644	NA
RH	0.010	0.659	0.015	0.989	NA
BP	1.360	1.438	0.946	0.444	75%
WIND	1.408	0.776	1.815	0.211	90%
DTF4	-85.550	19.533	-4.380	0.048	97.5%
ST4	5.701	1.448	3.938	0.059	97.5%
SM4	-1.852	4.497	-0.412	0.720	NA

CONDITION INDICES >30

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have opposite effects for the different sample points. This is so unlikely as to be virtually impossible, even given the differing soil types at the different sample points. The only independent variable that did not show a change in polarity was soil temperature. The coefficient for soil temperature ranged from 4 to 9; this is not an extreme variation, and this seems good evidence that soil temperature has caused most of the variation in the measured soil organic vapor concentration. This is the same conclusion reached by analysis of the linear regressions for each individual independent variable; thus it is apparent that among the measured variables, soil temperature has been the single most pronounced determinant of change in measured soil organic vapor concentration over the long term during this study.

Multiple Regression Results for Diurnal Data

The data from the diurnal study should be essentially unaffected by changes in soil temperature and depth to fluid. While soil moisture content could vary during this time span, it was not feasible to sample soils for moisture during each sample event because of the many samples collected during such a short time interval. Thus soil moisture was assumed to be constant, or at least exhibiting little enough change so as to have insignificant effect on measured soil vapor concentration.

The variables measured during the diurnal study were also modeled by multiple regression, and the resultant output of the model is listed in Table IX for SVP1, SVP2 and SVP4. As shown here, the model predicted the measured concentrations with far less accuracy, as indicated by the lower R2 values, especially for SVP2 and SVP4. Also, as in the multiple regression calculations for the long-term data, the coefficients for individual variables were of different polarities for the different sample points. Condition indices for these regression models were all much greater than 30, again indicating that two or more of the variables vary in a collinear fashion, and their effects may not be satisfactorily separated. In attempt to distinguish individual independent effects, each possible combination of independent variable were modeled (this resulted in 21 different model configurations). None of the models using other combinations of independent variables produced a higher R2 value than that with all the independent variables. Substantial variation was observed in the TIV readings during the diurnal study, which progressed in a regular manner as atmospheric conditions changed. Figure 137 shows the measured TIV values for each soil vapor port during the diurnal study. When compared to Figure 88, which shows the weather variables measured during diurnal sampling, the correlation of changing soil vapor concentration with atmospheric conditions appears obvious; however the interdependence of the atmospheric

TABLE IX

MULTIPLE REGRESSION CALCULATIONS RESULTS
DIURNAL DATA

SOIL VAPOR PORT 1

N: 16 MULTIPLE R: .934 MULTIPLE R2: .872

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	2254.805	483.833	4.660	0.001	99.5%
TEMP	0.190	0.390	0.488	0.635	NA
RH	0.279	0.136	0.311	0.762	NA
BP	-0.909	1.022	-0.890	0.393	75%
WIND	1.108	0.308	3.598	0.004	99.5%

CONDITION INDICES >30

SOIL VAPOR PORT 2

N: 16 MULTIPLE R: .784 MULTIPLE R2: .615

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	1154.023	1085.161	1.063	0.310	75%
TEMP	-0.256	0.874	-0.258	-0.292	NA
RH	0.095	0.305	0.311	0.762	NA
BP	-0.909	1.022	-0.890	0.393	74%
WIND	1.108	0.308	3.598	0.004	99.5%

CONDITION INDICES >30

SOIL VAPOR PORT 4

N: 16 MULTIPLE R: .539 MULTIPLE R2: .290

VARIABLE	COEFFICIENT	STD ERROR	T	P (2 TAIL)	CONFIDENCE LEVEL
CONSTANT	-625.933	943.510	-0.663	0.521	NA
TEMP	-0.509	0.760	-0.669	0.517	NA
RH	-0.438	0.265	-1.517	0.217	90%
BP	0.908	0.889	1.022	0.329	75%
WIND	-0.084	0.268	-0.313	0.760	NA

CONDITION INDICES >30

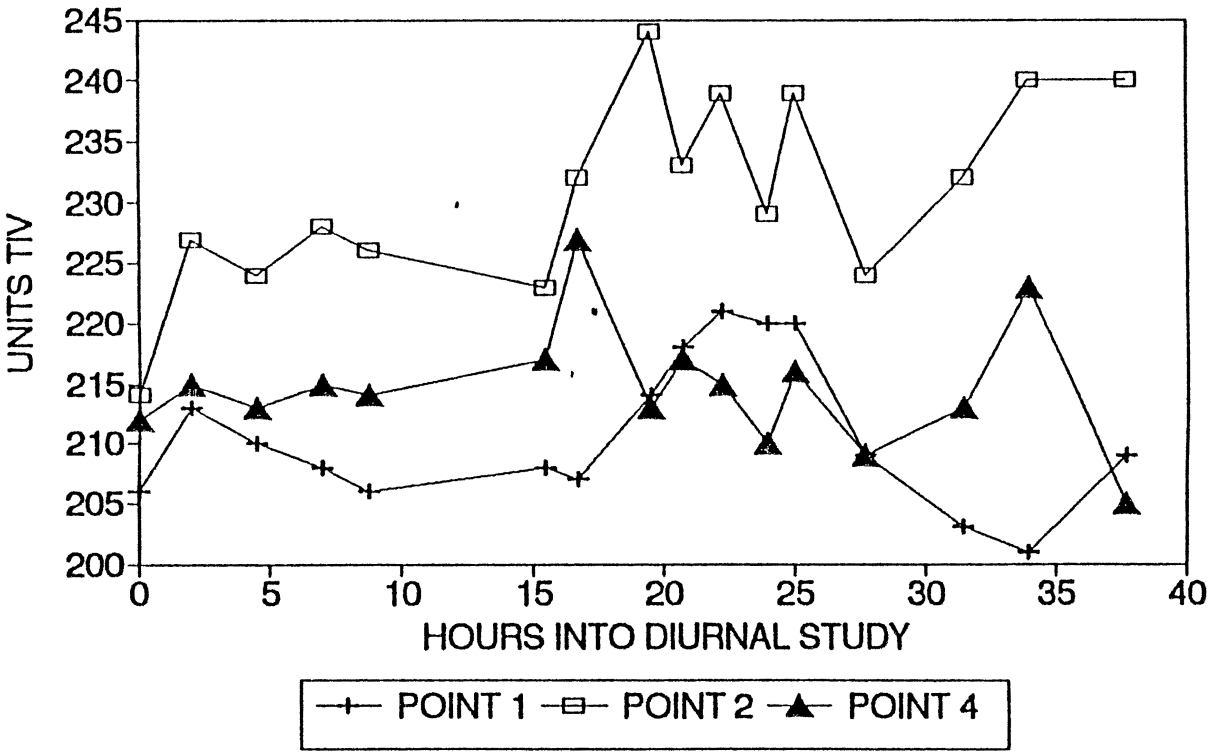


Figure 137. TIV measurements during diurnal sampling

variables makes it essentially impossible to distinguish their individual effects. However by using principles demonstrated by other research, a plausible empirical explanation may be developed. As shown by prior research, an increase in ambient temperature should result in a decrease in soil vapor concentration at a given distance above the volatile organic source; an increase in relative humidity should result in a decrease; an increase in temperature may be ruled out as a primary influence. The barometric pressure should result in a decrease; and an increase in wind speed should result in an increase. The observed effects over the diurnal cycle are in agreement with these expected results for sample points 1 and 2 with the exception of temperature. Therefore ambient relative humidity of soil vapor has been shown to consistently remain in the range from 98 to 100%; thus little effect would be expected from change in relative humidity at the depth of investigation. Therefore barometric pressure and wind speed must be the major influences of change in soil vapor concentration over the short term. Figure 84 (page 186) shows that wind speed usually varied in an opposite manner with barometric pressure during the diurnal study, thus their effects were usually complementary. However during the first 5 measurements wind speed did not vary measurably. The measured soil vapor concentration in soil vapor port 1 correlated negatively with barometric pressure, while the

measurements in vapor port 2 remained essentially unchanged during this period. Thus the effect of wind speed remains in question, and may be highly dependant on soil texture.

The problems with PID saturation (as discussed in the next section of this paper) may have contributed to the poor correlation between the observations at the different sampling points. The vapor samples from SVP1 did not saturate the PID during the diurnal study. Therefore these readings are considered to be the most accurate. The good negative correlation between barometric pressure change and change in measured soil vapor concentration in Vapor Port 1 supports the conclusion that barometric pressure change had a significant effect during this study. The general visual negative correlation for all the long term data (Figures 85 through 90 (pages 190 to 195) also support this conclusion. Thus the empirical conclusion is that barometric pressure was the secondary causation of variation in measured soil organic vapor concentration in this study.

Sources of Error

When sampling soil vapors, as when sampling any geologic material, problems are encountered in attempting to preserve the in-situ qualities of the sample. Since theoretically this is impossible, it is imperative to attempt to define the changes which occur, both to the sample and to the sampled environment as a result of the sampling or measurement process. In this study, core holes

were used to extract vapor samples. As discussed in Chapter II, the most accurate method of soil vapor sample collection is through a driven probe, using the lowest volume sample possible; this method creates the least disturbance to the soil and the solid-liquid-gas equilibria. However due to the low permeability of the soils at this site, it was not possible to retrieve a sample with this method. The "open core hole" method creates several problems: the soil vapor is inevitably exposed to and mixed with the ambient atmosphere; this exposure disturbs the vapor/source equilibria to some degree, and the sample collected is not actually pure soil vapor. The top of the open core hole was sealed with a soft rubber plug to inhibit leakage of ambient air into the core hole, but certainly some small amount of leakage occurred.

The open core hole may have also affected the soil environment over the long term, if the hole were not properly sealed, and were providing a "sink" for organic vapors to diffuse to the atmosphere. The concentration gradient would be altered around the core hole, instead of returning to the "pre-sampling" configuration, as would be expected if the core hole did not leak. The area surrounding the "leaking" core hole would be depleted of organic source material and the organic vapor concentration would decrease. Care was taken to prevent this happening by sealing the core holes with bentonite slurry, and this

is not considered to be a major source of error.

The organic vapor concentration changed with time as vapor was pumped from the core hole, generally first increasing then decreasing with time. Figure 138 illustrates a typical PID response with time when sampling a soil vapor port. The initial increase was interpreted to be due to purging of ambient air from the sampler plumbing and possibly from the core hole itself. The subsequent decrease was interpreted to be caused both by mixing with ambient air from leaks at the surface and by depletion of the organic vapors from the surrounding soil, or possibly by "saturation" of the PID electronics (this subject will be further discussed in later paragraphs). Regardless of the causes, the changing concentration created recording and interpretation problems. With measurements made at the site, the highest observed concentrations were recorded. It was reasoned that the highest concentration had to be the most accurate, since there was no external organic vapor source, and the soil organic vapor could only be diluted, not increased. Samples were also collected in 1-liter Tedlar bags. Since the sample in the bag is homogeneous, concentration does not change with time as vapor is pumped out; the concentration in the bag is the average of the changing concentrations as pumped from the core hole. This concentration is, however, different than that recorded during on-site sampling directly from the

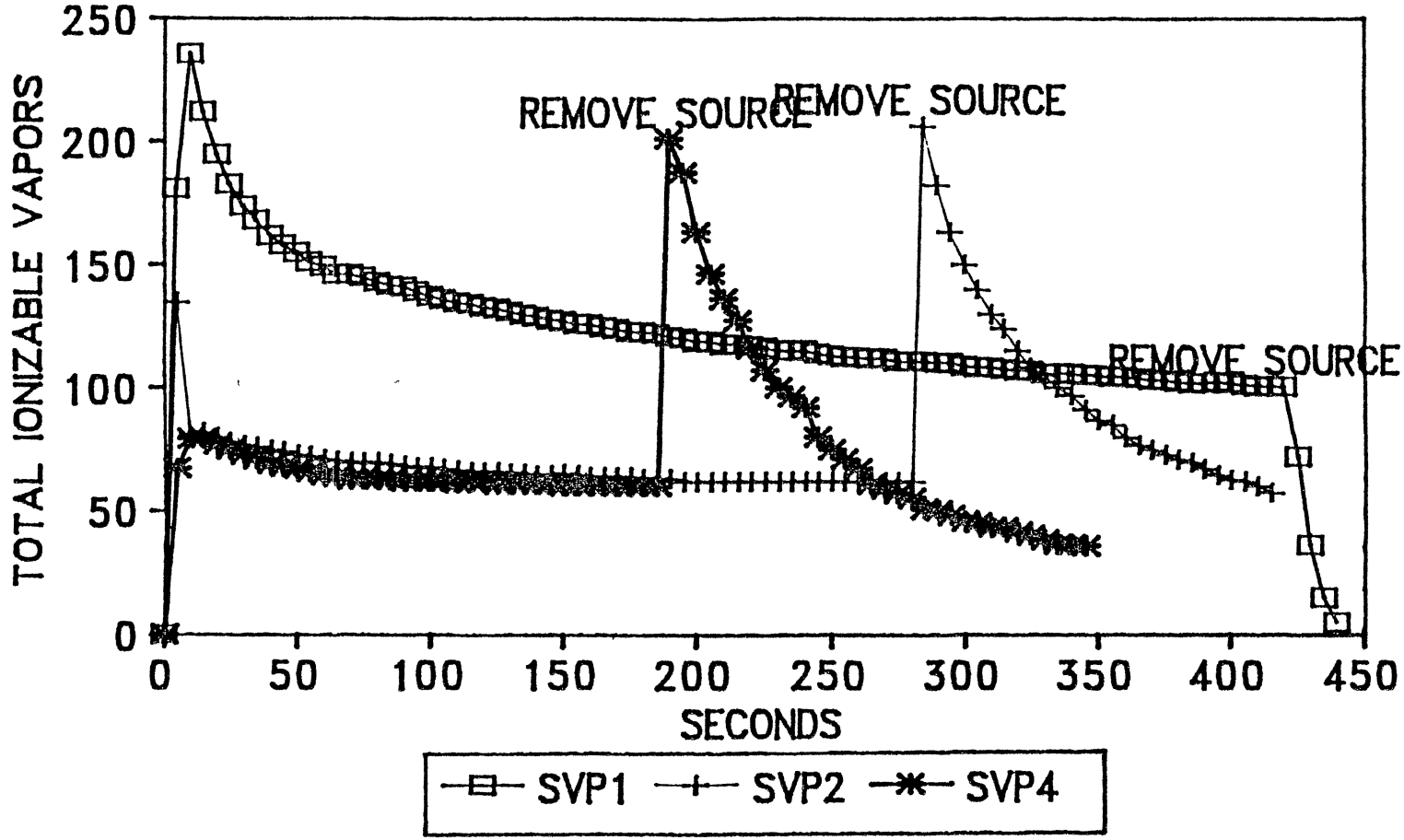


Figure 138. Graph showing change in PID response over time when sampling vapor ports 1, 2 and 4

core hole. Also the timing of sample collection will affect the concentration in the bag, and if samples are collected in differing timing regimes from different locations, the on-site and Tedlar bag sample concentrations will not correlate between locations. A poor correlation between on-site and Tedlar bag sample concentrations was sometimes observed, and sample timing may be an important cause of that discrepancy. Some Tedlar bags also leaked during transport. After these sources of error were recognized, more care was taken to duplicate sampling procedures and to test bags before use. Where Tedlar bag sample concentration was observed to be higher than that in the on-site sample, the higher of the concentrations was used, since it was reasoned that measurement error could only result in a decreased concentration. In other words, the PID could not measure what was not there, but dilution of the sample was a prominent possibility.

Some error was apparently introduced by the measurement instrument. It has been observed that the PID used for this study is adversely affected by high relative humidity, as described in Chapter IV. The manufacturer conducted a study to determine whether sample vapor humidity affected concentration readings with the instrument, by varying the relative humidity of the sample vapor and comparing OVM concentrations with those from an FID, which is not affected by humidity (Thermo-

Environmental Instruments, 1990). They determined that there was no appreciative humidity effect; however in their experiment they did not vary the temperature or humidity of the ambient air. It is this researcher's opinion that should this be done, an humidity-related effect will be observed. In addition to the humidity effect, the instrument sometimes failed to operate in the field due to a faulty battery. To eliminate this problem a different machine was used later in the study. Concentrations from the two machines may also differ, although no difference was observed using isobutylene calibration gas for a reference.

The PID also may have introduced error due to its apparent inability to accurately measure high concentrations. As illustrated by Figure 138, the PID apparently "saturates" at concentrations greatly exceeding 200 units, and indicates a concentration below 100 units. The concentration "decays" with time; upon removal from the source it jumps up, then again decays toward zero. The instrument manufacturer acknowledges this phenomenon, and has reportedly defeated the problem by diluting the sample input and slowly increasing sample concentration to achieve a "true" concentration (source: telephone conversation with Thermo-Environmental Instruments, February, 1991). This method was tested, but with poor results. A valve was inserted into the sample flow plumbing to allow the introduction of ambient air to dilute the vapor sample.

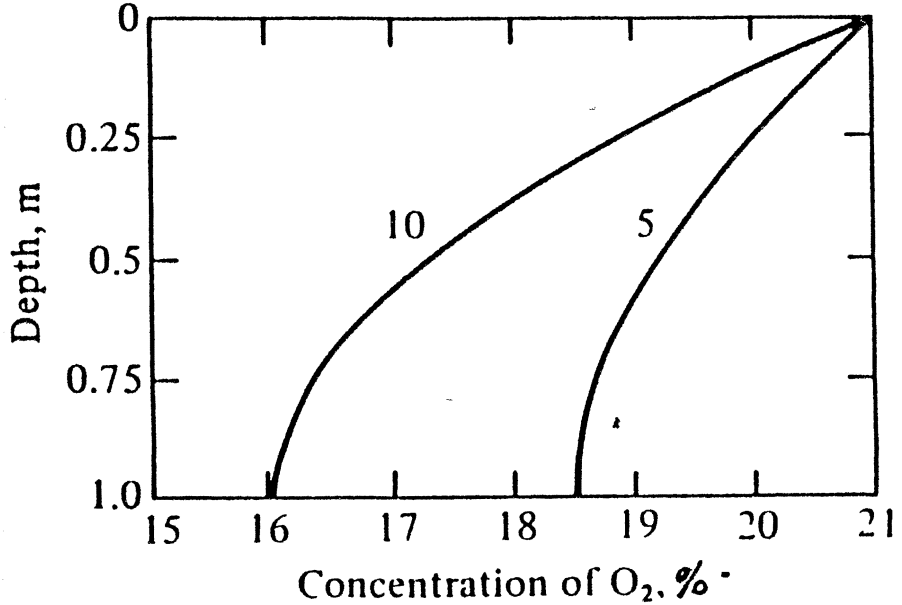
Concentration readings could be increased by allowing a small amount of ambient air into the vapor sample; however whenever the valve was completely closed the concentration immediately dropped and began to decay, as in Figure 138. It was suspected that this behavior may be due to the low oxygen content of the soil vapor, since the oxygen content of soil vapor is known to be less than that in the atmosphere (Marshall and Holmes, 1988). The highest concentration displayed by the PID for each sample event was used as the "true" concentration value; unfortunately this value may not actually represent true concentration, and it is not known whether it correlates in a predictable ratio to true concentration. This may be the single largest source of error in this study.

A combination oxygen meter-explosimeter was used to measure the oxygen content of vapor samples from soil ports 1, 2 and 4, as it was suspected that there may be an enhancement effect of oxygen in the photoionization process, and the low oxygen content of the soil vapor may be causing the PID to respond with a lower concentration. The soil vapor samples all contained a lower oxygen content than that of normal atmospheric conditions, 21 percent; SVP1 measured 13 percent oxygen, SVP2 measured 10% oxygen, and SVP4 measured 17% oxygen. However the oxygen content of the samples did not correspond with the PID attenuation. Two of these samples attenuated the PID; SVP2 and SVP4: the

lowest and highest of the three in oxygen content. The vapor sample from SVP1, while containing only 13% oxygen, did not attenuate the PID. The vapor from SVP1 also produced the lowest concentration when measured with the portable GC; SVP2 and SVP4 were both above 500 PPM total BTEX as measured with the portable GC. Thus high concentration, not low oxygen content, seems to be the cause of the PID attenuating.

This procedure did, however, suggest a valuable use for measurement of soil vapor oxygen content for quality control in soil vapor surveys. The oxygen content of soil vapor is known to decrease with depth, as shown by Figure 139. Soil vapor oxygen content is dependant on a number of factors, the most important being the rate of biotic activity in the soil, the diffusion coefficient of the soil, and depth (Marshall and Holmes, 1988). Soils with a lower diffusion coefficient (finer-grained soils) will contain less oxygen at correlative depths then coarser-grained soils. By measuring the oxygen content of soil vapor samples, and using knowledge of the soil texture, a determination may be made as to whether the soil probe has leaked, and atmospheric gasses have diluted the soil vapor sample. The increased biotic activity in the soil from the microbiotic oxidation of introduced organics would serve to lower the oxygen content; thus a maximum oxygen content would need to be established for particular soil types in

particular biotic activity regimes. More research is suggested to enable prediction of the relationship with adequate confidence.



Oxygen profiles in soil resulting from uniform activity to a depth of 1 m with respiration rates of 10 and 5 l m^{-2} day^{-1}. D/D_0 was taken to be uniformly 0.0625. (Currie, 1962.)

Figure 139. Graph showing change in soil oxygen content with depth

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

Research was conducted at a site in Oklahoma where gasoline has impacted ground water, to evaluate the measurement of organic vapors in soil and in ground water monitoring wells as a method for characterizing the impact to ground water by volatile organic chemicals. Research was also conducted to measure and attempt to isolate the effects of varying environmental conditions on the concentration of organic vapors in soil at a fixed point beneath the ground surface. The study site was chosen in part because of the large number of ground water monitor wells at the site, which provided an unusually dense hydrogeologic data base to utilize in interpreting observations.

A survey of soil volatile organic concentration was conducted across the site on a 75-foot spaced grid, at a depth of three feet below grade. A portable photoionization detector (PID) was used to measure volatile organic vapor concentrations in units of total ionizable vapors (TIV), from 1-inch diameter core holes with a specially designed vapor sampling tool. Equal

concentration values at sample stations on the grid were contoured to produce an isopleth map of soil TIV concentration. Site hydrogeologic parameters (aquifer grain size and historical ground water measurements) were analyzed to assist in interpretation of the soil vapor survey data.

Ground water samples were collected from selected monitor wells and analyzed by laboratory gas chromatography for concentrations of benzene, toluene, ethylbenzene and xylenes (BTEX). Areas of equal total BTEX concentration were also contoured and the resultant isoconcentration map compared to the TIV concentrations from the soil vapor survey for evaluation of the effectiveness of the soil vapor survey in identifying the extent and intensity of volatile hydrocarbon contamination in ground water. Areas of similar percentage of individual BTEX components in total BTEX were also contoured for analysis of the degree of spatial segregation of individual BTEX components and their implications on the relative age and movement of the volatile organic contamination.

The vapor in well casings was also sampled at 0.5 feet above fluid level and analyzed with a portable gas chromatograph for BTEX concentration. The resultant concentrations were contoured for comparison to the soil vapor TIV and ground water BTEX concentration and spatial distribution to determine the effectiveness of sampling

well headspace vapors to characterize volatile organic contamination in ground water.

Four "soil vapor ports" were installed in locations directly above and up-gradient and down-gradient to the floating hydrocarbon plume, for periodic measurement of soil vapor TIV concentration for comparison to varying environmental factors, and for analysis of the effectiveness of using soil vapor ports to monitor ground water volatile organic contamination. (One of these soil vapor ports was later abandoned after TIV readings decreased to immeasurable levels). Environmental factors measured for comparison were: ambient temperature, relative humidity, barometric pressure and wind speed, soil temperature, soil moisture and depth to phreatic fluid. The concentration of volatile organics in ground water was assumed to be constant for the purposes of this study. Soil moisture was measured as percent of total soil weight by dessication, using ASTM standard methods, in soil samples collected from 1-inch diameter cores located within 4 feet of the soil vapor ports. Vapor samples were collected periodically from these soil vapor ports over a five-month period, and more intensively over a 3-day period for analysis of long-term and short-term (diurnal) changes in volatile organic vapor concentration. Vapor samples were also collected from the soil core holes, for comparison of the "core-hole" method with the soil vapor port measurements, and as a fail-safe in case the soil

vapor ports did not provide reliable samples. Soil samples from the core holes were also analyzed by laboratory GC for BTEX, for comparison to ground water, well headspace and soil vapor samples. The soils were analyzed for grain size distribution by ASTM standard dry screening methods.

Statistical and graphical analysis was used to determine the effects of the changing environmental factors on soil volatile organic vapor (TIV) concentration at a fixed point beneath the surface. Linear regressions were calculated for each independent variable at each sample point, and multiple regression calculations were performed for all independent variables. The computer program SYSTAT was used for statistical calculations.

Conclusions

Soil Vapor Survey

The soil vapor survey defined the horizontal extent of volatile organic contamination in ground water quite adequately, as proven by the laboratory analyses of ground water samples. The concentration measured in soil vapor did not correlate well with BTEX concentration in ground water; however the soil vapor survey did identify areas of highest versus lower concentrations. The movement of volatile organics in ground water has apparently been limited to some extent by the finer-grained aquifer materials in the northwest of the study area. An area of

higher volatile organic concentration was also identified separate from the floating hydrocarbon plume, to the west-northwest. Historical ground water level measurements show that during May, 1990, a period of unusually high water table conditions, an ephemeral stream in the study area was in a gaining condition. Floating hydrocarbons apparently discharged with ground water during this period, flowing downstream and percolating into soils in the area where the "pod" of higher TIV concentrations were measured. Ground water analyses confirmed these findings. The apparent success of the soil vapor survey suggests that the "core hole" method of soil vapor sample collection may be a used as a viable alternative in areas where low-permeability soils prevent soil vapor sample collection through in-situ driven probes.

The portable photoionization detector provided an adequate means of identifying the vertical extent and delineating areas of highest volatile organic concentrations in ground water at this site. Problems were encountered with the PID, however, which have served to illustrate the limitations of this instrument for detailed field studies where stringent standards of accuracy and precision are required. The PID is also limited in its capacity to function under the widely varying atmospheric conditions encountered when in the field; extreme temperature and high humidity conditions will sometimes render the instrument inoperable. As long as these

problems are recognized, with proper preparation measures can be devised to overcome them in the field.

Ground Water, Well Headspace Vapor and Soil Analytical Results.

Analysis of the spatial distribution of BTEX components showed that the volatile hydrocarbon source at this site was of "medium" age, as determined by the degree of separation of BTEX components, which ruled out a "new" spill, and the relative abundance of volatiles, which ruled out an extremely aged spill. The percentage distribution of individual BTEX components in ground water was found to be reliably predictable by their physicochemical properties; their solubility and soil/water partition coefficients. The more soluble benzene, which also has a low soil/water partition coefficient, has travelled rapidly down-gradient while the xylenes and to some extent ethylbenzene, which both have lower solubilities and high soil/water partition coefficients, have remained in-place, adsorbed to soils. Toluene, which lies in between the other analytes in these properties, does not show as much segregation. No xylenes were detected in soil or well headspace vapor samples by the portable GC; this may be due to adsorption by the PVC well casing and soil vapor port tubing.

Total BTEX and individual BTEX components measured in well headspace by portable GC were usually higher, but

sometimes lower than in ground water. BTEX measured in soil vapor was also usually higher than, but sometimes lower than BTEX in soils. (The ubiquitous exception is xylenes, which were not detected in vapor samples). Soil vapor in units TIV as measured by the PID was also almost always higher than parts per million total BTEX in soil vapor, but was sometimes lower. Thus the different sampling methods did not provide a reliable numerical correlation with one another, and it was not possible to predict the respective concentrations of one another.

Correlation of Measured Soil Volatile Organic Vapor Concentrations with Changing Environmental Variables

Temperature. The TIV concentrations measured from soil vapor ports and corresponding core holes showed a generally increasing trend throughout the period of the study. Linear regression calculations showed a positive correlation (that is, soil vapor concentration increased with ambient temperature) for all data points for long-term data, all with better-than-random fit to the regression lines. Thus a positive correlation between ambient air temperature and soil vapor concentration at a fixed point below grade was indicated. The generally increasing trend for ambient temperature over the long term, however, was paralleled by soil temperature and relative humidity and opposed by barometric pressure; thus these collinear

variables may have created the same effect. Linear regression calculations for the diurnal data also showed a positive correlation between ambient temperature and soil vapor concentration in two of the three sample ports (the exception being port #4, SVP4). Goodness-of-fit to the regression line varied widely. The diurnal weather parameter measurements showed even stronger collinearity, and again the individual independent variable effects could not be adequately identified.

Barometric Pressure. Linear regression analyses showed a negative correlation (that is, soil vapor concentration increased as barometric pressure decreased) for all data sets except, again, the diurnal data for SVP4. Goodness-of- fit varied widely. The data shows a bimodal separation, which was probably due to a hiatus in sampling frequency during March and April. Visual inspection of the linear regression plots indicates a viable negative correlation for this variable. Based on the application of findings from previous research, the changes in vapor concentration during the diurnal study lead to the conclusion that at this site, barometric pressure had the largest effect on soil vapor concentration during the short term.

Relative Humidity. Linear regression analyses of the long-term data showed a positive correlation for relative humidity, and the calculations for diurnal data

showed a positive correlation for port 1 data, and a negative correlation for port 2 and 4 data. Goodness-of-fit was poor for all regressions. Any apparent correlation with relative humidity is believed to be a covariant effect of ambient temperature.

Wind Speed. The linear regressions for wind speed resulted in both positive and negative correlations at the same sample point with soil organic vapor concentration. Goodness-of-fit was very low for all data sets except for the diurnal data from SVP2, which fit fairly well. The effect of wind speed remains uncertain as based on the data from this study.

Soil Moisture Content. The linear regressions for this variable produced both negative and positive correlations, and goodness-of fit was very low. Apparently varying soil moisture had little effect on measured soil vapor concentration at this site. There may have been too little variation in this variable to produce a measurable effect, due to the shallow water table at the site.

Depth to Fluid. The linear regressions for this variable also produced both negative and positive correlations, and goodness-of fit was very low with the exception of the data from SVP4. This variable was expected to have a strong effect, as it has been shown by other researchers to have a strong negative correlation to

soil organic vapor concentration. The poor correlation here suggests that the primary source of the measured organics in soil at this site may not be the ground water, but the soil itself. The historically high water table in the area has apparently allowed hydrocarbons and/or volatiles dissolved in ground water to adsorb onto soils.

Soil Temperature. All linear regressions showed a relatively strong positive correlation with soil temperature, and goodness-of-fit was the best for any of the measured variables. The multiple regression calculations, while indeterminate because of insoluble collinearity problems, also produced consistent positive correlations, with similar coefficients for soil temperature. There is little question that among the measured variables, soil temperature was the single largest factor affecting the measured concentration of organic vapors over the long term in soil at this site.

The findings of this study suggest that monitoring soil vapor as an indicator of changes in concentration of volatile organics in ground water could present very difficult or insurmountable problems in data interpretation. This study has shown that at this site, soil vapor concentration does change measurably in response to changing environmental parameters, both over the diurnal cycle and seasonally. Therefore it would be necessary to separate those variable effects from the effect of the

variable of interest, which is the concentration of volatiles in ground water. This site is by no means ideal for the application of soil vapor monitoring as a means of remotely monitoring ground water quality; the method could work well where ground water is deeper and soils are not directly contaminated. However the study at this site shows that the concept must be approached with caution.

Soil vapor oxygen content was measured in attempt to determine the reasons for the unexplained photoionization detector malfunction. This procedure suggested the possibility that soil vapor oxygen content may be used as a quality-control measure in soil vapor surveys, to determine whether the soil vapor probe has leaked and allowed the dilution of the soil vapor sample with ambient air. More research is suggested to further evaluate this concept.

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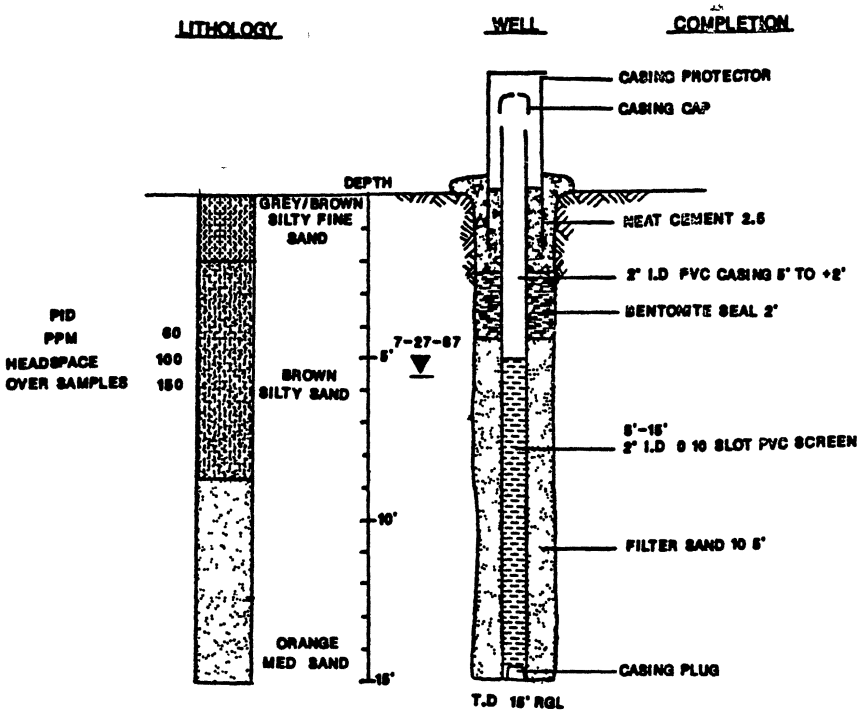
APPENDIX A

LITHOLOGY LOGS FOR MONITOR WELLS AT STUDY SITE

[redacted]

NEW WELL LABEL BMW1

MONITOR WELL TA1-1
7-27-87



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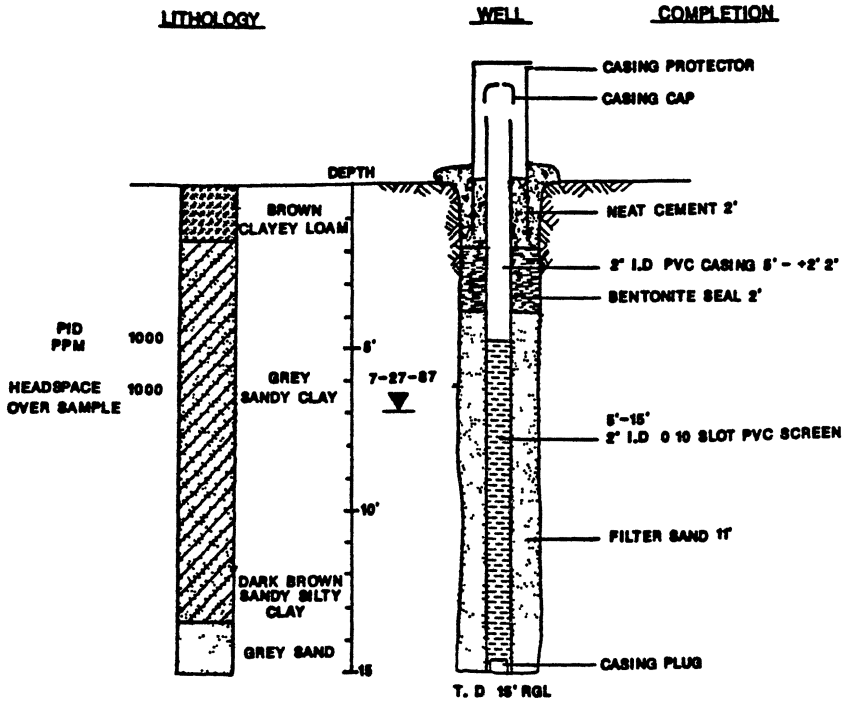
MONITOR WELL TA1-2
7-27-87

NEW WELL LABEL BMW2



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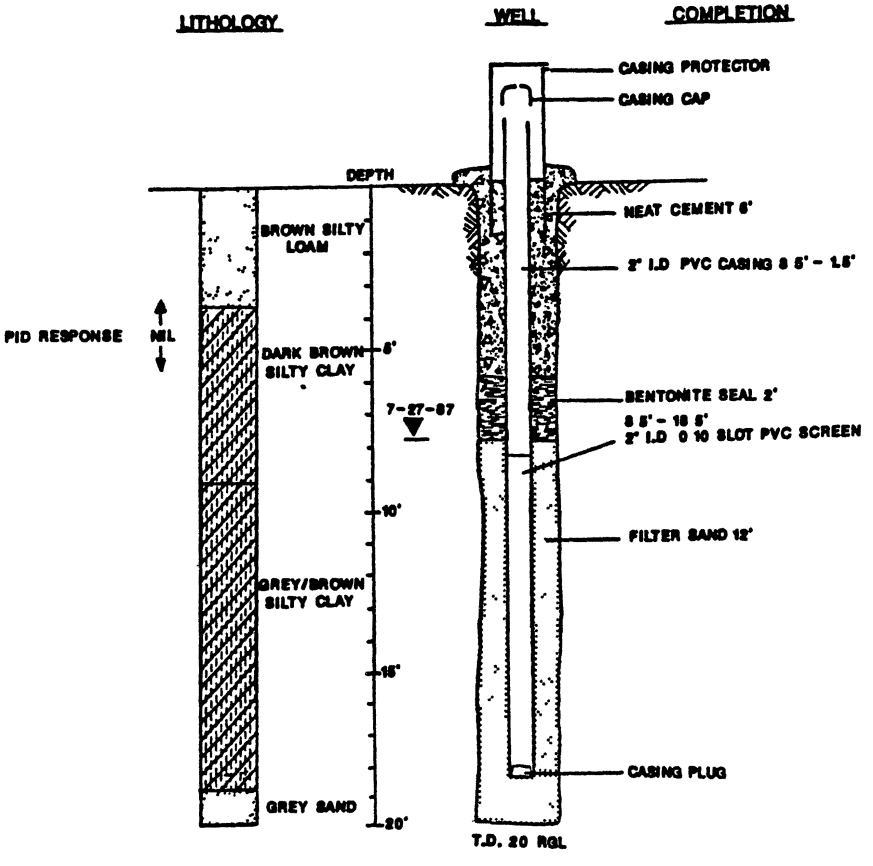
NEW WELL LABEL BMW3

MONITOR WELL TA1-3
7-27-87



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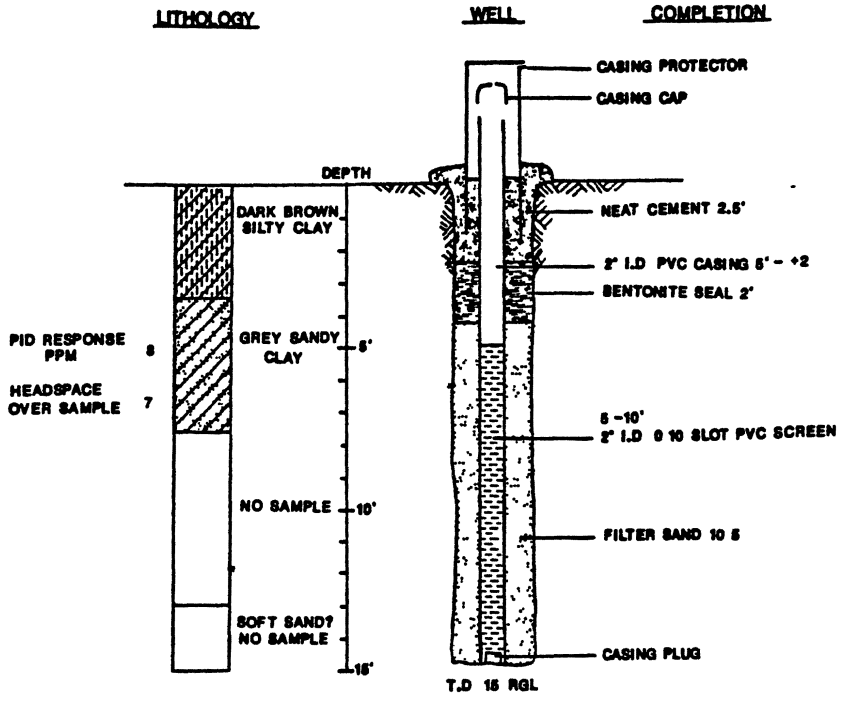
NEW WELL LABEL BMW4

MONITOR WELL TA1-4
7-28-87



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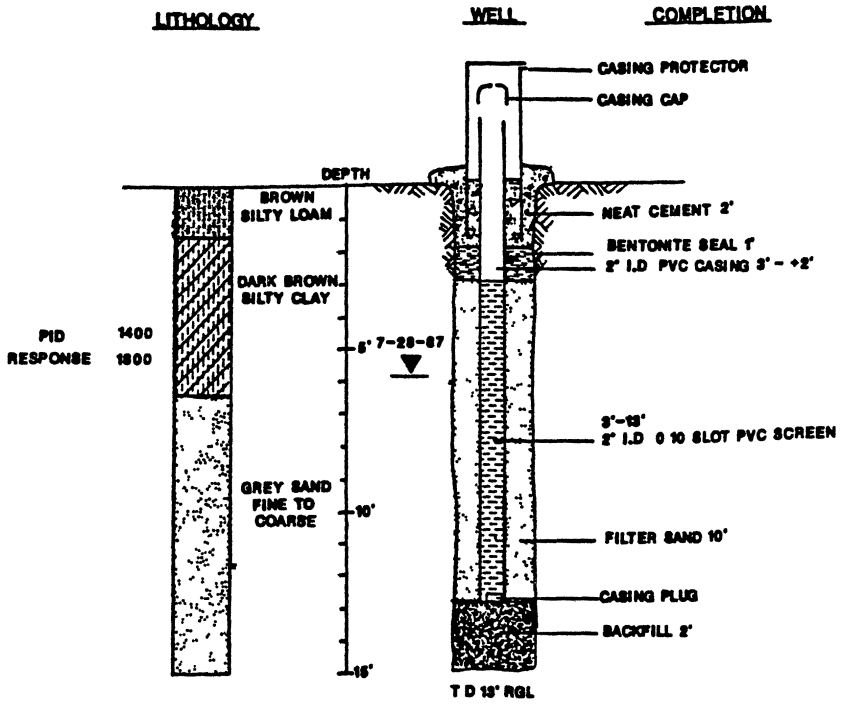
NEW WELL LABEL BMW5

MONITOR WELL TSAB-5/W5
7-28-87



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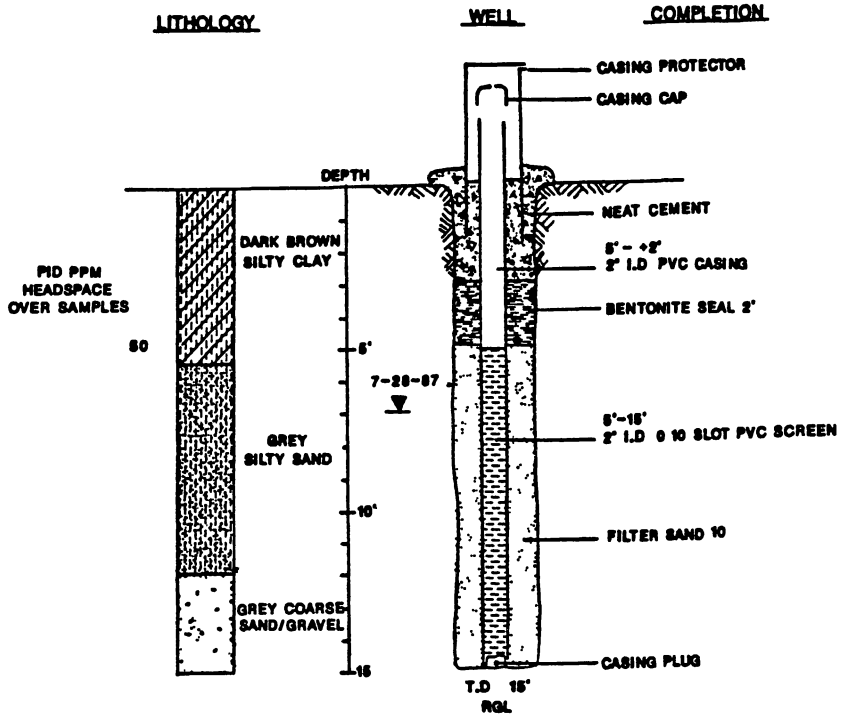
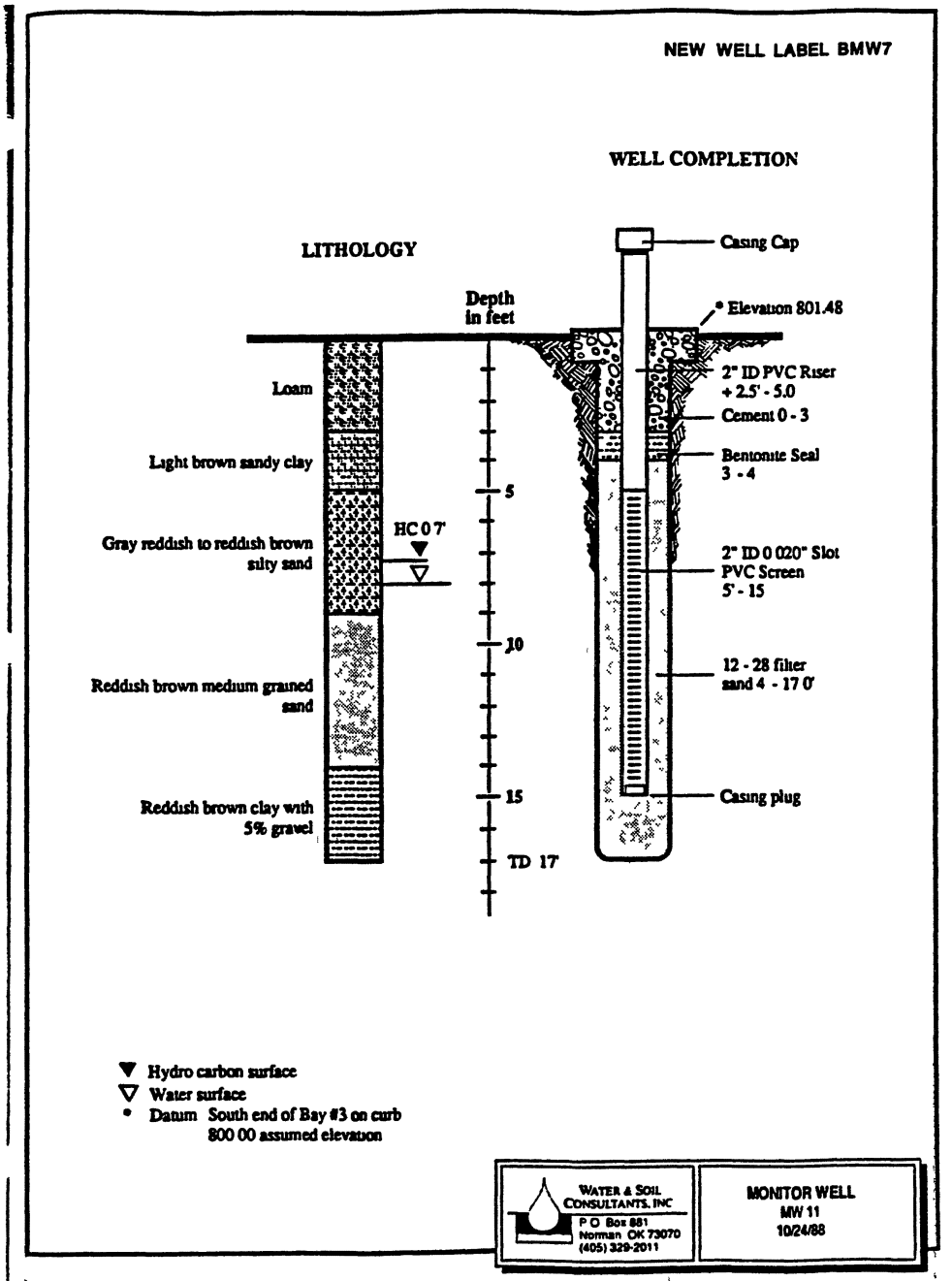
NEW WELL LABEL BMW6

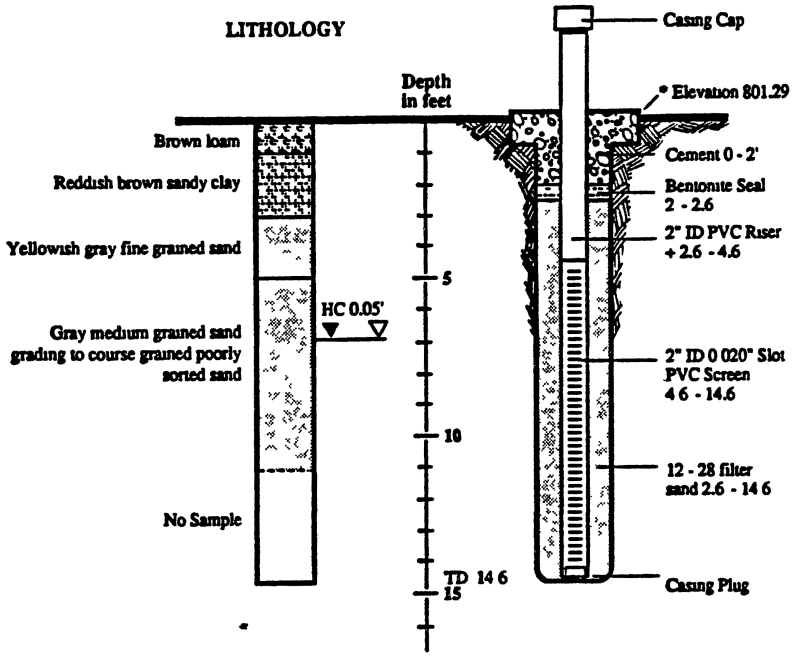
MONITOR WELL TSAB-6/W6
7-28-87




NEW WELL LABEL BMW7
WELL COMPLETION
LITHOLOGY
Depth in feet
Casing Cap
Elevation 801.48
2" ID PVC Riser + 2.5' - 5.0
Cement 0 - 3
Bentonite Seal 3 - 4
2" ID 0.020" Slot PVC Screen 5' - 15
12 - 28 filter sand 4 - 17.0'
Casing plug
Loam
Light brown sandy clay
Gray reddish to reddish brown silty sand
Reddish brown medium grained sand
Reddish brown clay with 5% gravel
HC 0 7'
5
10
15
TD 17'
Hydro carbon surface
Water surface
Datum South end of Bay #3 on curb 800 00 assumed elevation
WATER & SOIL CONSULTANTS, INC
P O Box 881
Norman OK 73070
(405) 329-2011
MONITOR WELL
MW 11
10/24/88

NEW WELL LABEL BMW8

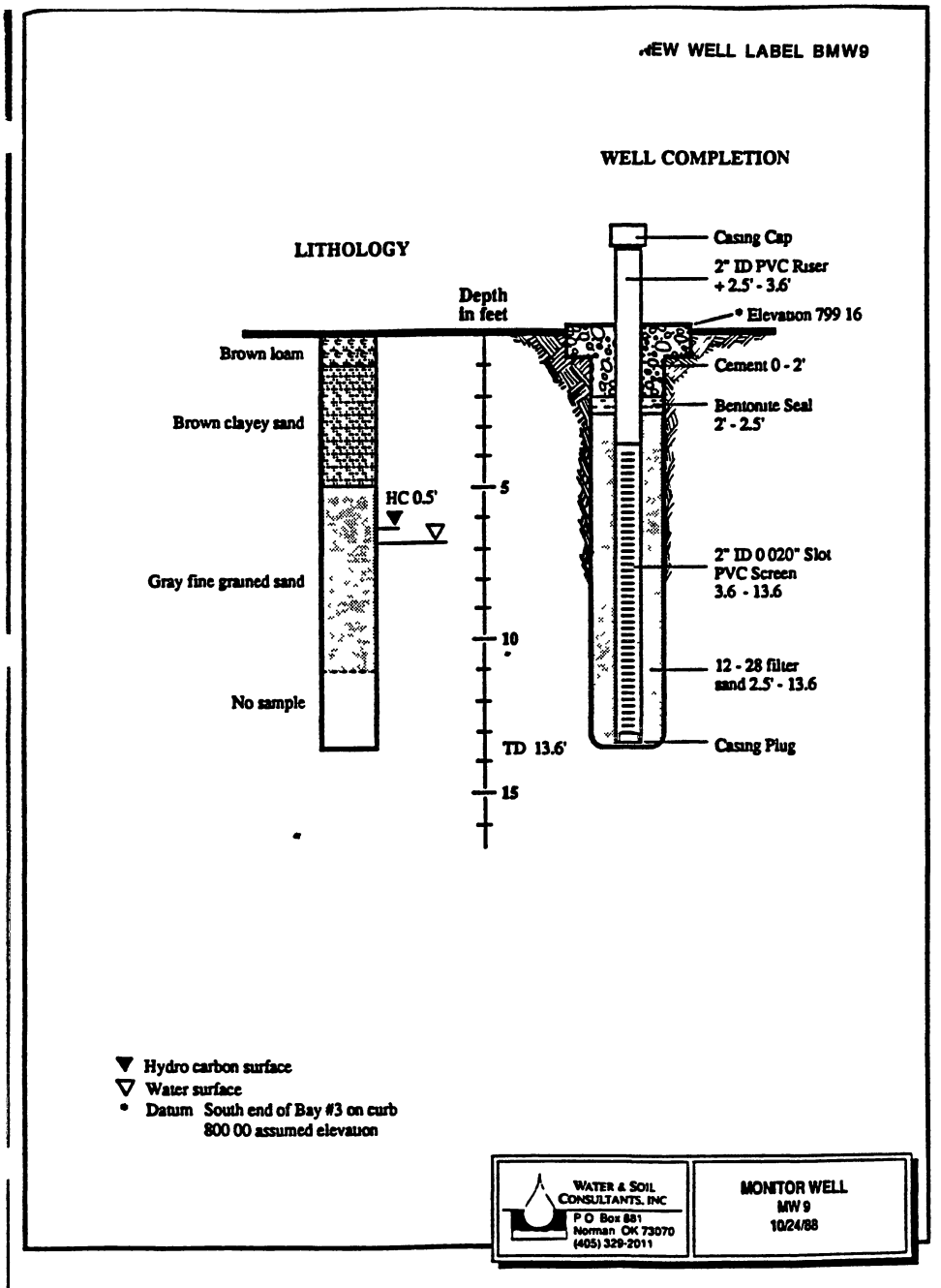
WELL COMPLETION

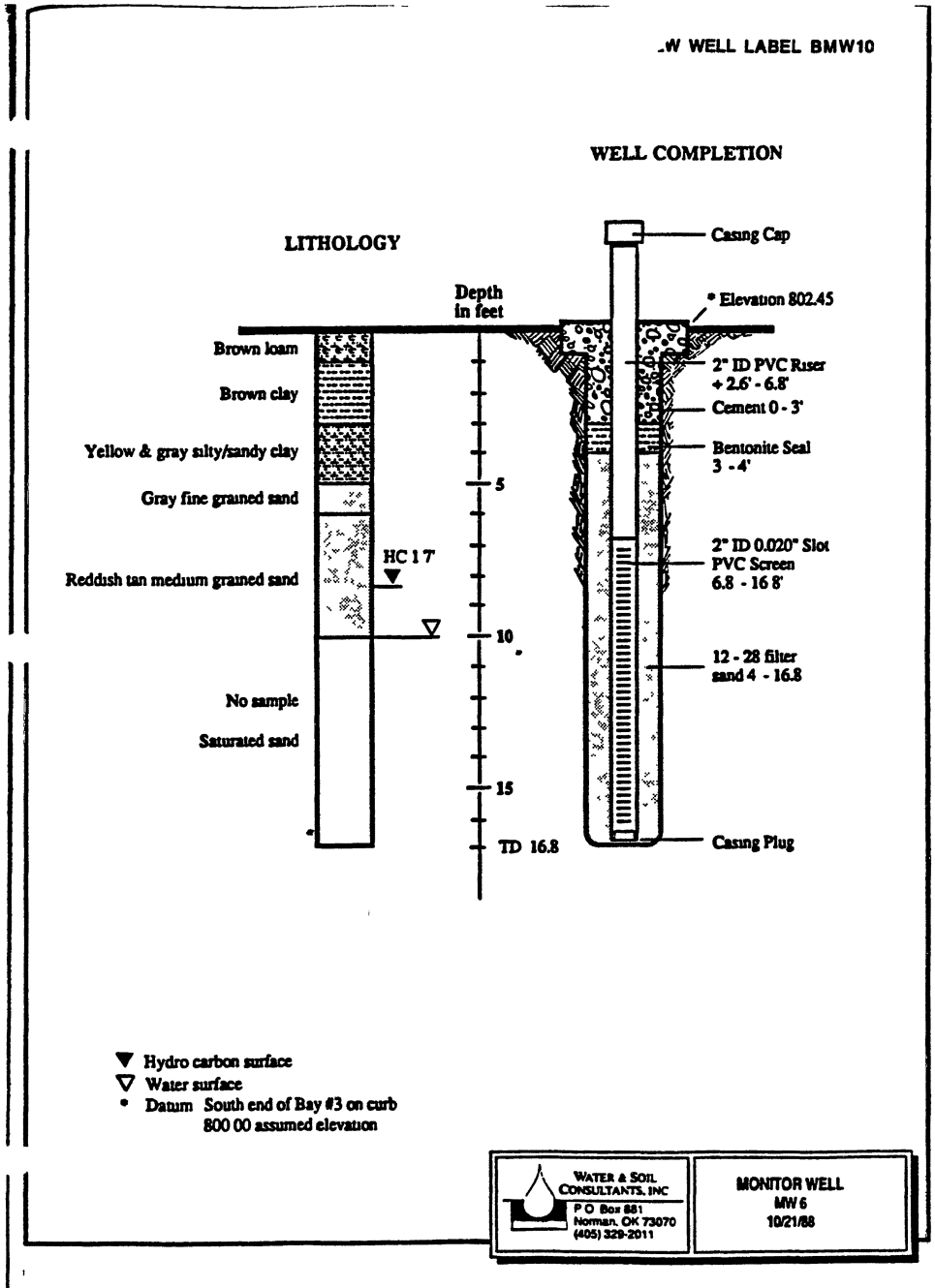


▼ Hydro carbon surface
▽ Water surface
• Datum South end of Bay #3 on curb 800 00 assumed elevation

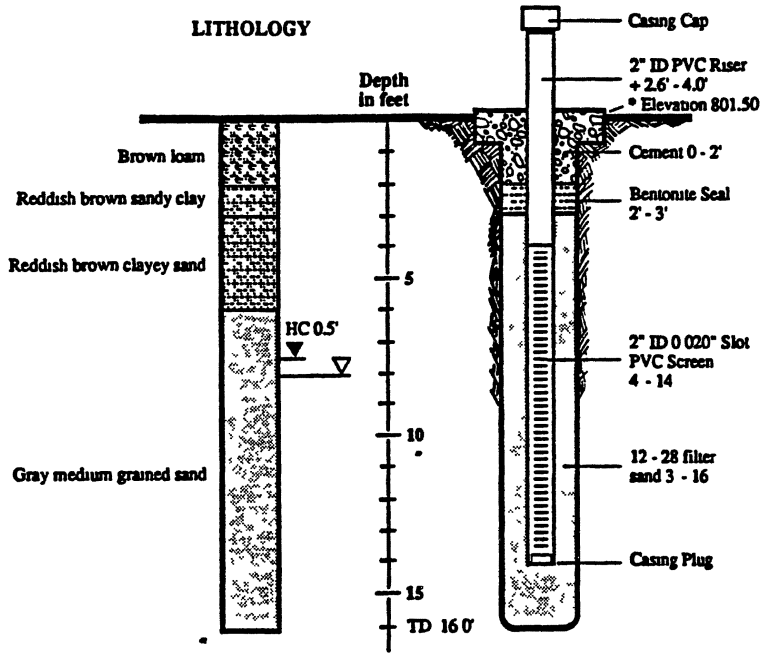
WATER & SOIL CONSULTANTS, INC
P O Box 861
Norman, OK 73070
(405) 329 2011

MONITOR WELL
MW 7
10/24/88


NEW WELL LABEL BMW9
WELL COMPLETION
LITHOLOGY
Depth in feet
Brown loam
Brown clayey sand
Gray fine grained sand
No sample
HC 0.5'
5
10
TD 13.6'
15
Casing Cap
2" ID PVC Riser + 2.5' - 3.6'
* Elevation 799 16
Cement 0 - 2'
Bentonite Seal 2' - 2.5'
2" ID 0 020" Slot PVC Screen 3.6 - 13.6
12 - 28 filter sand 2.5' - 13.6
Casing Plug
▼ Hydro carbon surface
▽ Water surface
• Datum South end of Bay #3 on curb 800 00 assumed elevation
WATER & SOIL CONSULTANTS, INC
P O Box 881
Norman OK 73070
(405) 329-2011
MONITOR WELL
MW 9
10/24/88


..W WELL LABEL BMW10
WELL COMPLETION
LITHOLOGY
Depth in feet
Casing Cap
* Elevation 802.45
Brown loam
Brown clay
Yellow & gray silty/sandy clay
Gray fine grained sand
Reddish tan medium grained sand
No sample
Saturated sand
HC 1 7'
2" ID PVC Riser + 2.6' - 6.8'
Cement 0 - 3'
Bentonite Seal 3 - 4'
2" ID 0.020" Slot PVC Screen 6.8 - 16 8'
12 - 28 filter sand 4 - 16.8
Casing Plug
5
10
15
TD 16.8
▼ Hydro carbon surface
▽ Water surface
* Datum South end of Bay #3 on curb 800 00 assumed elevation
WATER & SOIL CONSULTANTS, INC
P O Box 881
Norman, OK 73070
(405) 329-2011
MONITOR WELL
MW 6
10/21/88

-W WELL LABEL BMW11



▼ Hydro carbon surface
▽ Water surface
• Datum South end of Bay #3 on curb
800 00 assumed elevation

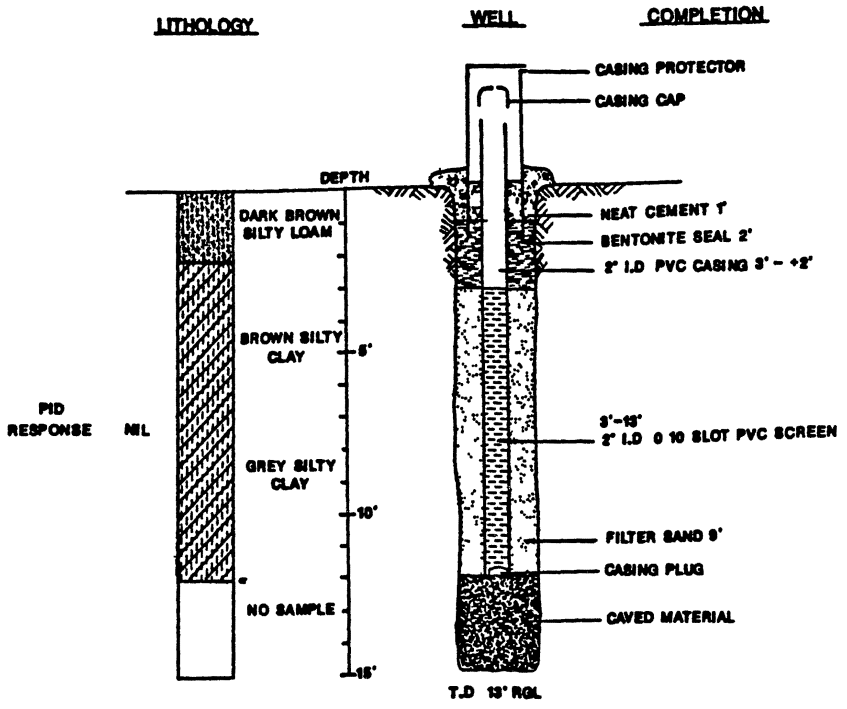
WATER & SOIL CONSULTANTS INC
P O Box 881
Norman, OK 73070
(405) 329-2011

MONITOR WELL
MW 3
10/21/88

[redacted]

NEW WELL LABEL BMW12

MONITOR WELL TASB-4/W3
7-28-87



BMW13

SOIL BORING LOG KM—5655-A

[redacted] Hydrology Dept Engineering Services | KM SUBSIDIARY [redacted] | LOCATION WINNEWOOD, OK | BORING NUMBER B1-2

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	TYPE	DEPTH	REC.	REMARKS OR FIELD OBSERVATIONS
2.7	SILT, V.F. SANDY, SL CLAYEY, RD-BRN, MOIST (WET IN FIRST 4'), FRIABLE, NO ODOR		ML			1		4'	4	
4.9	SAND, VF-F GRAIN, SILTY, MODERATELY W. GRADED, MOIST, LOOSE, NO ODOR		SM							
5	SAND, F-CRS GRAIN, DK RED-BROWN, WELL GRADED, WET TO SATURATED LOOSE, NO ODOR		SW			2		9'	2.7'	▽ 5.6' SAMPLE COMPACTED
10	(NO SAMPLE ASSUME SAND, AS ABOVE, GRADING TO SAND/GRAVEL, UP TO 3/8" DIAMETER, WELL GRADED)					3		14'	0'	SAND FLOWED INTO AUGERS - 1 - BAILED SAND LOOSE, NO -HI-E
15	AS ABOVE									SAMPLING FROM ANNULUS WITH CENTER -
20										

EXPLANATION

- ▼ Water Table (24 Hour)
- ▽ Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC. Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED 3/8/90 | PAGE 1 of 2

DRILLING METHOD HOLLOW STEM AUG

DRILLED BY WINNEK/M POWELL

LOGGED BY TIM BEN

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES

BMW14

SOIL BORING LOG KM-5655-A

[redacted] KM SUBSIDIARY
Hydrology Dept Engineering Services

LOCATION: WYNNEWOOD OK
BORING NUMBER: E2-2

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	SOIL SAMPLE TYPE	SOIL SAMPLE DEPTH	SOIL SAMPLE REC.	REMARKS OR FIELD OBSERVATIONS
0					0.0					
19	SANDY SILT, DARK RED-BROWN, VERY FINE GRAIN, MOIST, FRIABLE, SOFT, NO ODOR		ML		0.0					
3.5	CLAY, SILTY, RED-BROWN, FIRM-HARD, LOW PLASTICITY, MOIST, NO ODOR		CL		0.0	1		4'	3'	
4.8			ML		0.0					
5	SILT, SANDY, RED-BROWN, MOIST, FRIABLE, SOFT, NO ODOR				0.0					
	SAND, RD BRN, VF-F. GR, WET TO SAT, FRI, LOOSE, NO ODOR, MOD P GRD		SP		0.0	2		9'	4.1'	
10 (est)					0.0					▽ 10.0
10.1	LAYER OF BANDED DK GRY & RD.-BRN CRS GR. SD, SAT, NO ODOR		SP		0.0					
	SAND, RD-BRN., F-CRS GR, SAT, NO ODOR, W. GRDD.		SW		0.0	3		14'	2.0'	
14	TD 14'				0.0					
15					0.0					NO FREE PRODUCT IN HOLE

EXPLANATION

- ▼ Water Table (24 Hour)
- ▽ Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED: 3/7/90
PAGE: 1 of 1
DRILLING METHOD: HOLLOW STEM AUGER
DRILLED BY: WINNEK / M. POWELESS
LOGGED BY: TIM BENT
EXISTING GRADE ELEVATION (FT AMSL):
LOCATION OR GRID COORDINATES:

SOIL BORING LOG KM-5655-A

BMW 15

[redacted] Hydrology Dept Engineering Services

LOCATION: WYNNEWOOD, OK

BORING NUMBER: B3-1

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	SOIL SAMPLE TYPE	SOIL SAMPLE DEPTH	SOIL SAMPLE REC	REMARKS OR FIELD OBSERVATIONS
1.3	SILT, DK BRN, SDY., SL. CLYY, SOFT, FRI, MOIST, NO ODOR		ML		0					
3.1	CLYY SLT - SLTYCLAY, RD-BRN, FRM.-HD, FRI, MOIST, SL. SDY, NO ODOR		ML		0					
5	SAND, RD.-BRN., VF.-F GR, MOIST, LOOSE, MOD. W GRD, NO ODOR		SW		0	1		4.5	4.6	
6.7										▽ 6.7'
	SAND, F-CRS GR, RD-BRN., SAT., W. GRD, NO ODOR		SW		0	2		9.5	3.4	Bottom 2' of Sample compressed
10	TD 9.5'									NO FREE PRODUCT IN HOLE

EXPLANATION

- ▼ Water Table (24 Hour)
- ▽ Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND
- _____
- _____

DATE DRILLED: 3/7/90 | PAGE: 1 of 1

DRILLING METHOD: HOLLOW STEM AUGER

DRILLED BY: WINNEK/M. POWELL

LOGGED BY: T. BENT

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES

SOIL BORING LOG KM-5655-A

BMW16 [redacted]

Hydrology Dept Engineering Services [redacted]

LOCATION: WYNNEWOOD, OK

BORING NUMBER: B4-1

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	SOIL SAMPLE TYPE	SOIL SAMPLE DEPTH	SOIL SAMPLE REC	REMARKS OR FIELD OBSERVATIONS
4.5	SILT, DK RED-BROWN, SLIGHTLY SANDY (VFG), SL CLAYEY, GRADING TO LIGHT BROWN, BECOMING SANDIER WITH DEPTH, MOIST, NO ODOR		ML		0	1		4.5'	4.5'	
7.0	SILTY SAND, LT RED-BROWN, TAN MOTTLED, VERY FINE GRAIN, MOD WELL GRADED, MOIST TO WET, NO ODOR		SM		0	2		9.5	4.1	SAMPLE 1" BELOW 0.25 ▽
10	SAND LIGHT RED BROWN, FINE TO COARSE GR AT TOP, FINING TO VF-F GR @ 9', WET, SATURATED IN LOWER 0.5' SLI ODOR IN BASIN		SW		0	3				
14.5	SAND LIGHT RED BROWN TO TAN, F-CRS GR, WELL GRADED, SAT TRACE HC ODOR, FLOWING		SW		0			14.5'	1.5	FOR 1 HOUR DUE TO FLOWING SAN
15	TD 14.5'									NO FREE PRODUCT IN HOLE

EXPLANATION

- ▼ Water Table (24 Hour)
- ▽ Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED: 3/7/90

PAGE: 1 of 1

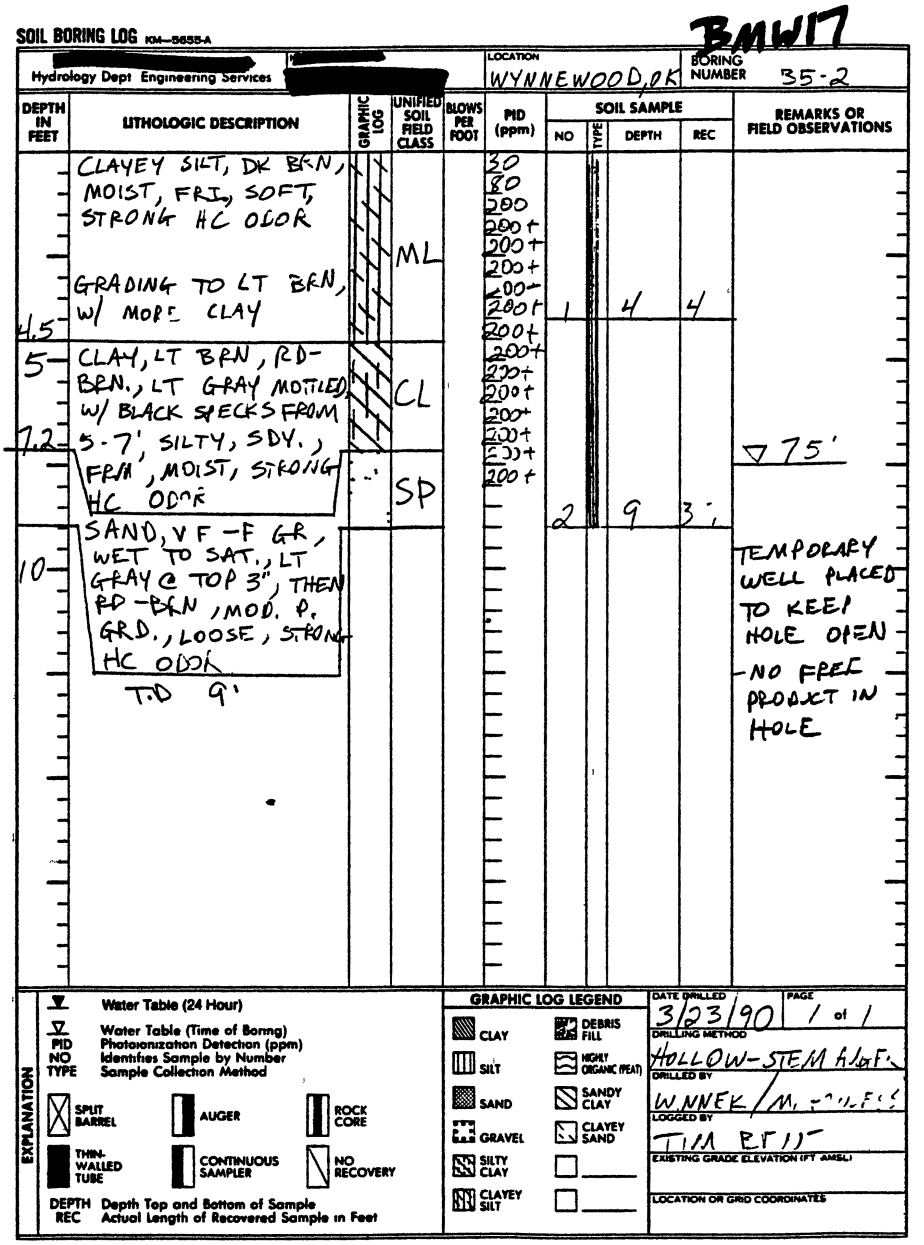
DRILLING METHOD: HOLLOW STEM AUGER

DRILLED BY: WINNEK / MIDDLE

LOGGED BY: TIM T-T

EXISTING GRADE ELEVATION (FT. AMSL)

LOCATION OR GRID COORDINATES



SOIL BORING LOG KM-5655-A

BMW17

Hydrology Dept Engineering Services [redacted]

LOCATION WYNNEWOOD, OK

BORING NUMBER 35-2

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	SOIL SAMPLE TYPE	SOIL SAMPLE DEPTH	SOIL SAMPLE REC	REMARKS OR FIELD OBSERVATIONS
	CLAYEY SILT, DK BRN, MOIST, FRI, SOFT, STRONG HC ODOR		ML		30 80 200 200+ 200+ 200+ 200+					
4.5	GRADING TO LT BRN, W/ MORE CLAY				200+	1		4	4	
5	CLAY, LT BRN, RD-BRN., LT GRAY MOTTLED W/ BLACK SPECKS FROM 5-7', SILTY, SDY., 7.2 FRM, MOIST, STRONG HC ODOR		CL SP		200+ 200+ 200+ 200+ 200+ 200+ 200+					▽ 75'
	SAND, V F - F GR, WET TO SAT., LT GRAY @ TOP 3", THEN RD-BRN, MOD. P. GRD., LOOSE, STRONG HC ODOR					2		9	3"	
10	T.D 9'									TEMPORARY WELL PLACED TO KEEP HOLE OPEN - NO FREE PRODUCT IN HOLE

EXPLANATION

- ▼ Water Table (24 Hour)
- ▽ Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED 3/23/90 PAGE 1 of 1

DRILLING METHOD HOLLOW-STEM AUGER

DRILLED BY WINNEK / M. [illegible]

LOGGED BY TIM BRITT

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES

SOIL BORING LOG KM—8655-A

[redacted] Hydrology Dept - Engineering Services [redacted]

LOCATION: WYNNEWOOD, OK

BORING NUMBER: BMW 19

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	SOIL SAMPLE TYPE	SOIL SAMPLE DEPTH	SOIL SAMPLE REC	REMARKS OR FIELD OBSERVATIONS
	SILT, DK BRN, CLYY, MOIST, SOFT, FI', CLAY CONTENT INCREASING WITH DEPTH, COLOR BECOMING TAN-BROWN		ML							LOGGING ROTARY CUTTINGS FROM FINE (USNA FROM 1'-5' ML, 8' 3'-)
5	SILTY CLAY, CL, SDY, MOIST, SOFT - FAIRLY HIGH PLASTICITY, RED BROWN & GRAY MOTTLED		CH							
10										
	SAND, RED-BROWN & GRAY, V F.-F. GR, MOD P. GR.		SP							
15	AS ABOVE, WITH GRAVEL UP TO 3/8' DIA, V W GRD		SW							
20										

EXPLANATION

- Water Table (24 Hour)
- Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND
- ____
- ____

DATE DRILLED: 4/17/97 PAGE: 1 of 2

DRILLING METHOD: ROTARY AIR

DRILLED BY: WINNER/BOB NICK

LOGGED BY: TM ERNST

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES

SOIL BORING LOG KM-5655-A

[redacted] LOCATION WYNNFWOD1.OK BORING NUMBER BMW18

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	TYPE	DEPTH	REC	REMARKS OR FIELD OBSERVATIONS
20	SAND AND GRAVEL, AS ABOVE		SW							
	THIN LAYER OF DARK BROWN PEATY SOIL		OL							
	CLAYEY SILT, DARK TO MEDIUM GRAY & DARK REDDISH BROWN MOTTLED, FIRM TO HARD, LO PLASTICITY, NO ODOR		ML			1	X	- - -	-	
25										
26						2		26	1.5'	
27	ARKOSIC SAND & GRAVEL, LIGHT GRAY WITH DARK GRAVEL, FRIABLE, POSSIBLY LIKELY		SW							SET 6' PVC SURFACE IF 15 @ 30
32	CLAYEY SILT, GRAY & REDDISH BROWN MOTTLED, HARD, LOW PLASTICITY, SOMEWHAT FISSILE									CONTINUE DRLG 4/18/19 W/ 5 1/4" BIT, FRESH POTABLE WATER
35										
	AS ABOVE									
40										

EXPLANATION

- Water Table (24 Hour)
- Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC PEAT
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED 4/17&18/19 PAGE 2 of 4

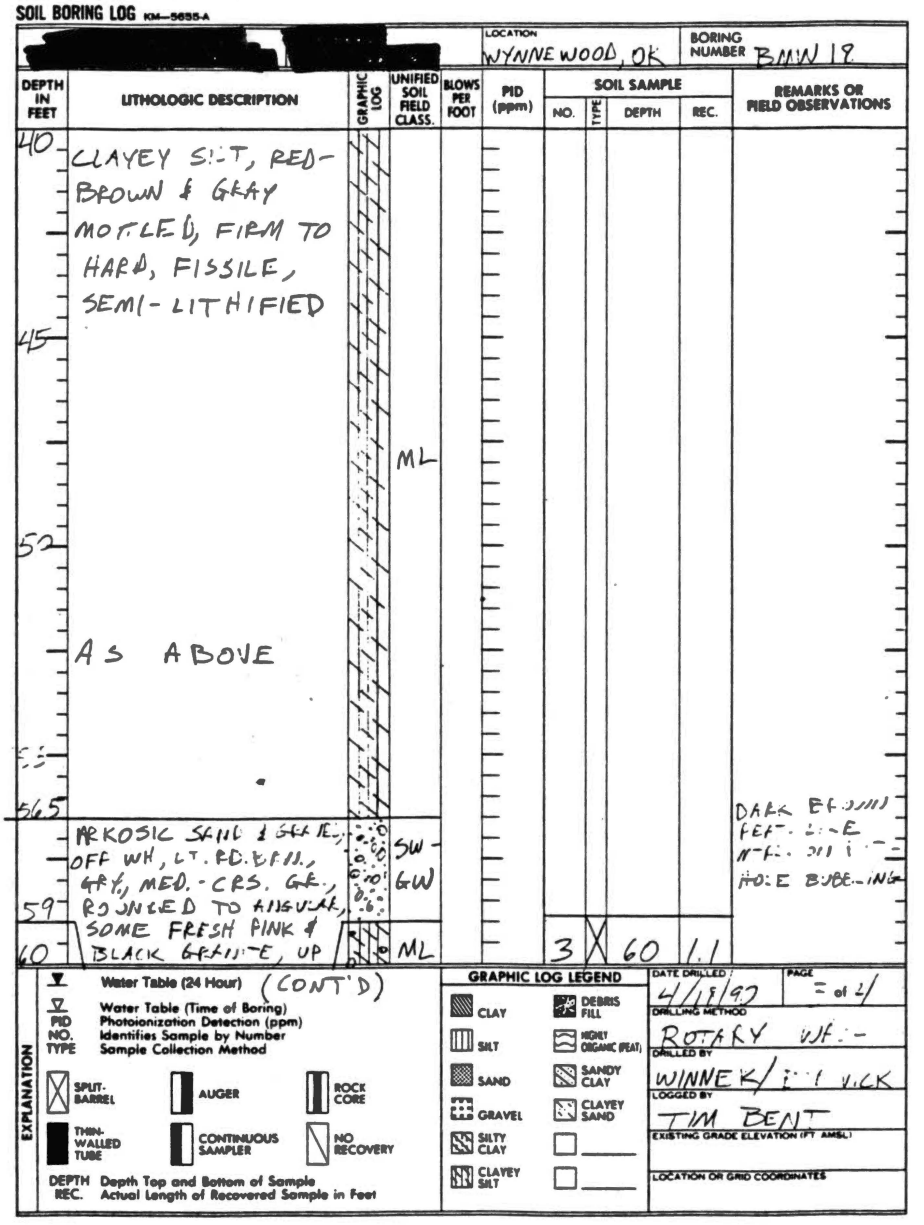
DRILLING METHOD ROTARY WASH

DRILLED BY WINNEK/ED. IC

LOGGED BY TIM BENT

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES



SOIL BORING LOG KM-5655-A

[redacted]

LOCATION: WYNNEWOOD, OK

BORING NUMBER: BMW 18

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS.	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO.	SOIL SAMPLE TYPE	SOIL SAMPLE DEPTH	SOIL SAMPLE REC.	REMARKS OR FIELD OBSERVATIONS
40	CLAYEY SILT, RED-BROWN & GRAY MOTTLED, FIRM TO HARD, FISSILE, SEMI-LITHIFIED									
45			ML							
52	AS ABOVE									
56.5	ARKOSIC SAND & GRAVEL, OFF WH, LT. RD. BRN., GRY., MED.-CRS. GR., ROUNDED TO ANGULAR, SOME FRESH PINK & BLACK GRANITE, UP		SW-GW							DARK BROWN FERRUGINOUS STAIN NOTE BUBBLING
59										
60			ML			3	X	60	1.1	

(CONT'D)

EXPLANATION

- Water Table (24 Hour)
- Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO. Identifies Sample by Number
- TYPE Sample Collection Method
  - SPLIT-BARREL
  - AUGER
  - ROCK CORE
  - THIN-WALLED TUBE
  - CONTINUOUS SAMPLER
  - NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC. Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED: 4/15/92

PAGE: 2 of 2

DRILLING METHOD: ROTARY WASH

DRILLED BY: WINNEKA DRILLING

LOGGED BY: TIM BENT

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES

SOIL BORING LOG KM—5655-A

Hy[redacted] Services [redacted]

LOCATION: WYNNEWOOD, OK

BORING NUMBER: BMW18

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	SOIL SAMPLE TYPE	SOIL SAMPLE DEPTH	SOIL SAMPLE REC	REMARKS OR FIELD OBSERVATIONS
60	TO 1" DIA GRAY & DARK RED-BROWN MOTTLED CLAYEY SILTY SOFT SHALE, WITH GRAVEL IMBEDDED, UP TO 1" DIA									
65										
70	AS ABOVE, WITHOUT GRAVEL									
75	T D. 75'.									NO FREE PRODUCT IN HOLE

EXPLANATION

- Water Table (24 Hour)
- Water Table (Time of Boring)
- PID — Photoionization Detection (ppm)
- NO — Identifies Sample by Number
- TYPE — Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH — Depth Top and Bottom of Sample
- REC — Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED: 4/8/90

PAGE: 4 of 4

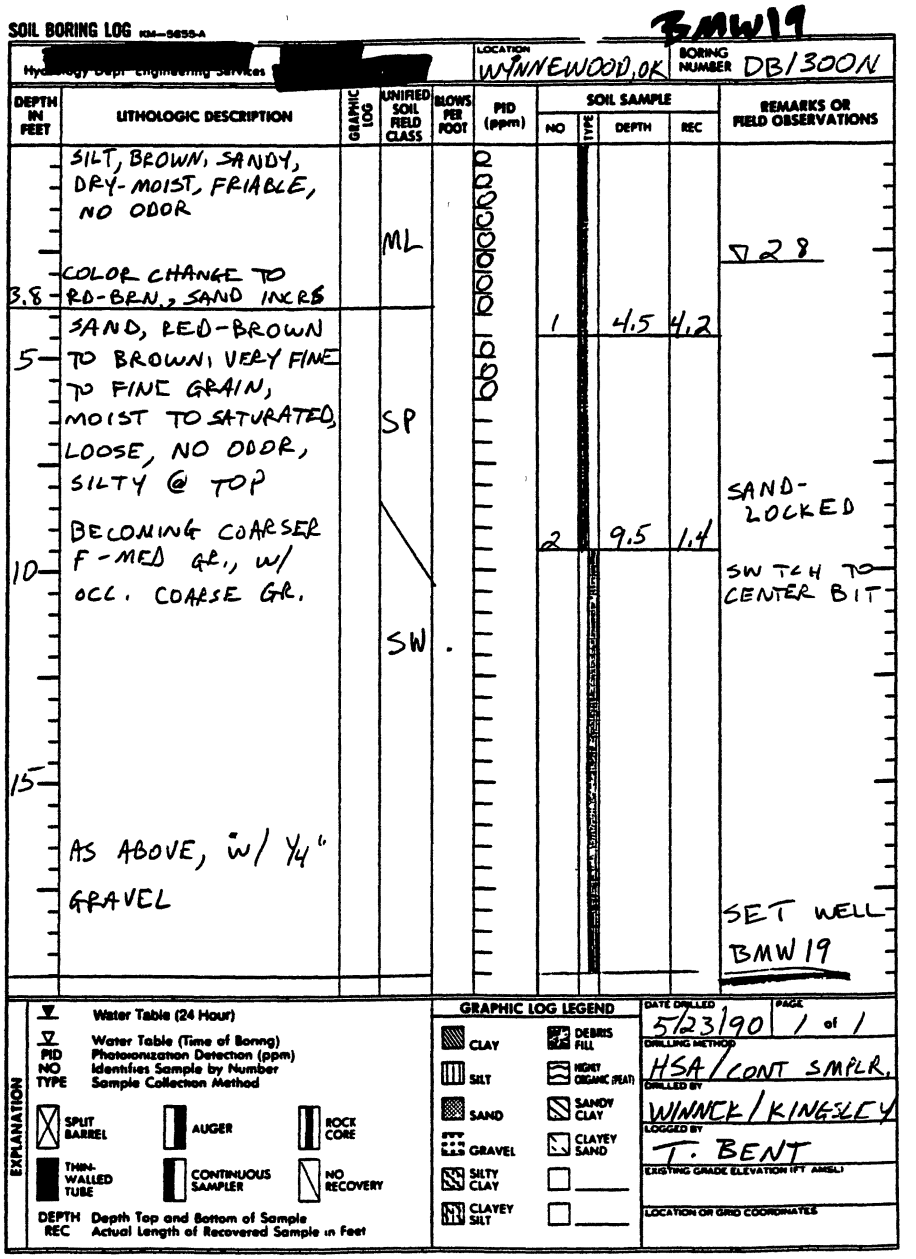
DRILLING METHOD: ROTARY WASH

DRILLED BY: WINNEK / BOB VICK

LOGGED BY: TIM BENT

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES



SOIL BORING LOG KM—5655-A

BMW19

Hydrology Dept- Engineering Services [redacted]

LOCATION WYNNEWOOD, OK

BORING NUMBER DB/300N

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO	TYPE	DEPTH	REC	REMARKS OR FIELD OBSERVATIONS
	SILT, BROWN, SANDY, DRY-MOIST, FRIABLE, NO ODOR		ML							▽ 2 8
3.8	COLOR CHANGE TO RD-BRN, SAND INCRS					1		4.5	4.2	
5	SAND, RED-BROWN TO BROWN; VERY FINE TO FINE GRAIN, MOIST TO SATURATED, LOOSE, NO ODOR, SILTY @ TOP		SP							SAND-LOCKED
	BECOMING COARSER F-MED GR., W/ OCC. COARSE GR.		SW			2		9.5	1.4	SW TCH TO CENTER BIT
15	AS ABOVE, W/ ¼" GRAVEL									SET WELL BMW19

EXPLANATION

- ▼ Water Table (24 Hour)
- ▽ Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED 5/23/90 PAGE 1 of 1

DRILLING METHOD HSA/CONT SMPLR.

DRILLED BY WINNEK/KINGSLEY

LOGGED BY T. BENT

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES

SOIL BORING LOG KM-5655-A

BMW20

[redacted] Engineering Services

LOCATION WINNEWOOD, OK

BORING NUMBER DB1800N

DEPTH IN FEET	LITHOLOGIC DESCRIPTION	GRAPHIC LOG	UNIFIED SOIL FIELD CLASS	BLOWS PER FOOT	PID (ppm)	SOIL SAMPLE NO.	SOIL SAMPLE TYPE	SOIL SAMPLE DEPTH	SOIL SAMPLE REC.	REMARKS OR FIELD OBSERVATIONS
0	SILT, DK BRN., MOIST, SOFT, FRIABLE, NO ODOR		ML		0					
2.0					0					▽ 2.4
	CLAYEY SILT - SILTY CLAY, DK RD.-BRN., MOIST, SOFT-FIRM, MOD PLASTIC, NO ODOR		MH-CH		0					
5					0	1		4.5	4.5	
										NO SAMPLE
	CLAY, GRAY-BROWN, WET, V. HIGH PLAST, SOFT, NO ODOR		CH			2		9.5	0	
10										SWITCH TO CENTER BIT
	GRAVELLY SAND, CLR-ORNG.-TAN-BROWN, MED-CRS. GR., UP TO 3/4" GRAVEL, ARKOSIC, W. GRD, SAT., NO ODOR		SW					14.5		
15										
	CLAY, RD.-BRN., W/ GRY. MTLG., SLTY, SL. SDY, HARD, LOW PLAST,		CL					19.5		SET WELL BMW20
	TD 19.5'									

EXPLANATION

- ▼ Water Table (24 Hour)
- ▽ Water Table (Time of Boring)
- PID Photoionization Detection (ppm)
- NO Identifies Sample by Number
- TYPE Sample Collection Method
- SPLIT BARREL
- AUGER
- ROCK CORE
- THIN-WALLED TUBE
- CONTINUOUS SAMPLER
- NO RECOVERY
- DEPTH Depth Top and Bottom of Sample
- REC Actual Length of Recovered Sample in Feet

GRAPHIC LOG LEGEND

- CLAY
- SILT
- SAND
- GRAVEL
- SILTY CLAY
- CLAYEY SILT
- DEBRIS FILL
- HIGHLY ORGANIC (PEAT)
- SANDY CLAY
- CLAYEY SAND

DATE DRILLED 5/22/90

PAGE 1 of 1

DRILLING METHOD HOLLOW-STEM AUGER

DRILLED BY WINNEK/KINGSLEY

LOGGED BY T BENT

EXISTING GRADE ELEVATION (FT AMSL)

LOCATION OR GRID COORDINATES

APPENDIX B

WATER LEVEL INFORMATION USED FOR CONSTRUCTION OF HYDROGEOLOGIC MAPS

BULK FUEL LOADING FACILITY
WELL DATA, 12-12-90

WELL NAME	TOC ELEV	STICK-UP	GROUND ELEV	DEPTH TO PRODUCT (TOC)	DEPTH TO PRODUCT (RGL)	PRODUCT THICK-NESS	PRODUCT SPECIFIC GRAVITY	DEPTH TO WATER (TOC)	DEPTH TO WATER (RGL)	PRODUCT ELEV	WATER ELEV	CORREC-TED WATER ELEV	CORRECTED DEPTH TO WATER (RGL)
BMW1	844.77	2.17	842.6					6.43	4.26		838.34	838.34	4.26
BMW2	841.65	1.85	839.8	5.48	3.63	0.04	* Q_s.7509	5.52	3.67	836.17	836.13	836.16	3.64
BMW3	840.21	1.61	838.6					7.99	6.38		832.22	832.22	6.38
BMW4	838.31	2.21	836.1					7.67	5.46		830.64	830.64	5.46
BMW5	843.92	1.22	842.7	6.29	5.07	0.39	0.8395	6.68	5.46	837.63	837.24	837.57	5.13
BMW6	844.73	2.33	842.4	7.29	4.96	0.02	0.8395	7.31	4.98	837.44	837.42	837.44	4.96
BMW7	845.79	2.19	843.6	8.05	5.86	0.16	0.7509	8.21	6.02	837.74	837.58	837.70	5.90
BMW8	845.64	2.24	843.4	7.54	5.3	0.01	0.7509	7.55	5.31	838.1	838.09	838.10	5.30
BMW9	843.6	2.5	841.1	7.44	4.94	0.01	0.7509	7.45	4.95	836.16	836.15	836.16	4.94
BMW10	846.86	2.36	844.5	8.91	6.55	0.09	0.7509	9	6.64	837.95	837.86	837.93	6.57
BMW11	845.78	2.38	843.4	8.46	6.08	0.01	0.7509	8.47	6.09	837.32	837.31	837.32	6.08
BMW12	841.55	2.35	839.2					6.15	3.8		835.4	835.40	3.80
BMW13	846.33	2.56	843.77					7.89	5.33		838.44	838.44	5.33
BMW14	848.71	2.55	846.16					10.73	8.18		837.98	837.98	8.18
BMW15	846.91	2.69	844.22					9.59	6.9		837.32	837.32	6.90
BMW16	846.57	2.75	843.82					9.57	6.82		837	837.00	6.82
BMW17	842.03	2.63	839.4					6.26	3.63		835.77	835.77	3.63
BMW19	844.04	1.84	842.2					8.21	6.37		835.83	835.83	6.37
BMW20	837.6	2.32	835.28					5.63	3.31		831.97	831.97	3.31

BULK FUEL LOADING FACILITY
WELL DATA, 4-23-91

WELL NAME	TOC ELEV	STICK-UP	GROUND ELEV	DEPTH TO PRODUCT (TOC)	DEPTH TO PRODUCT (RGL)	PRODUCT THICK-NESS	PRODUCT SPECIFIC GRAVITY	DEPTH TO WATER (TOC)	DEPTH TO WATER (RGL)	PRODUCT ELEV	WATER ELEV	CORREC-TED WATER ELEV	CORRECTED DEPTH TO WATER (RGL)
BMW1	844.77	2.17	842.6					6.68	4.51		838.09	838.09	4.51
BMW2	841.65	1.85	839.8	5.54	3.69	0.02	0.7509	5.56	3.71	836.11	836.09	836.11	3.69
BMW3	840.21	1.61	838.6					7.58	5.97		832.63	832.63	5.97
BMW4	838.31	2.21	836.1					6.68	4.47		831.63	831.63	4.47
BMW5	843.92	1.22	842.7	6.5	5.28	0.3	0.8395	6.8	5.58	837.42	837.12	837.37	5.33
BMW6	844.73	2.33	842.4	7.48	5.15	0.06	0.8395	7.54	5.21	837.25	837.19	837.24	5.16
BMW7	845.79	2.19	843.6	8.44	6.25	0.14	0.7509	8.58	6.39	837.35	837.21	837.32	6.28
BMW8	845.64	2.24	843.4	7.81	5.57	0.01	0.7509	7.82	5.58	837.83	837.82	837.83	5.57
BMW9	843.6	2.5	841.1	7.08	4.58	0.01	0.7509	7.09	4.59	836.52	836.51	836.52	4.58
BMW10	846.86	2.36	844.5	9.26	6.9	0.09	0.7509	9.35	6.99	837.6	837.51	837.58	6.92
BMW11	845.78	2.38	843.4	8.7	6.32	0.01	0.7509	8.71	6.33	837.08	837.07	837.08	6.32
BMW12	841.55	2.35	839.2					6.17	3.82		835.38	835.38	3.82
BMW13	846.33	2.56	843.77					8.15	5.59		838.18	838.18	5.59
BMW14	848.71	2.55	846.16					10.98	8.43		837.73	837.73	8.43
BMW15	846.91	2.69	844.22					9.78	7.09		837.13	837.13	7.09
BMW16	846.57	2.75	843.82					9.81	7.06		836.76	836.76	7.06
BMW17	842.03	2.63	839.4					6.34	3.71		835.69	835.69	3.71

BULK FUEL LOADING FACILITY
WELL DATA, 5-22-90

WELL NAME	TOC ELEV	STICK-UP	GROUND ELEV	DEPTH TO PRODUCT (TOC)	DEPTH TO PRODUCT (RGL)	PRODUCT THICK-NESS	PRODUCT SPECIFIC GRAVITY	DEPTH TO WATER (TOC)	DEPTH TO WATER (RGL)	PRODUCT ELEV	WATER ELEV	CORREC-TED WATER ELEV	CORRECTED DEPTH TO WATER (RGL)
BMW1	844.77	2.17	842.6					3.09	0.92		841.68	841.68	0.92
BMW2	841.65	1.85	839.8	3.21	1.36	0.15	0.7509	3.36	1.51	838.44	838.29	838.40	1.40
BMW3	840.21	1.61	838.6					6.6	4.99		833.61	833.61	4.99
BMW4	838.31	2.21	836.1					5.43	3.22		832.88	832.88	3.22
BMW5	843.92	1.22	842.7	1.9	0.68	4.57	0.8395	6.47	5.25	842.02	837.45	841.29	1.41
BMW6	844.73	2.33	842.4	3.95	1.62	0.22	0.8395	4.17	1.84	840.78	840.56	840.74	1.66
BMW7	845.79	2.19	843.6	4.6	2.41	0.2	0.7509	4.8	2.61	841.19	840.99	841.14	2.46
BMW8	845.64	2.24	843.4				0.7509	3.87	1.63		841.77	841.77	1.63
BMW9	843.6	2.5	841.1	4.05	1.55	0.1	0.7509	4.15	1.65	839.55	839.45	839.53	1.57
BMW10	846.86	2.36	844.5	4.96	2.6	0.37	0.7509	5.33	2.97	841.9	841.53	841.81	2.69
BMW11	845.78	2.38	843.4	4.76	2.38	0.11	0.7509	4.87	2.49	841.02	840.91	840.99	2.41
BMW12	841.55	2.35	839.2					4.4	2.05		837.15	837.15	2.05
BMW13	846.33	2.56	843.77					4.33	1.77		842	842.00	1.77
BMW14	848.71	2.55	846.16					6.54	3.99		842.17	842.17	3.99
BMW15	846.91	2.69	844.22					5.77	3.08		841.14	841.14	3.08
BMW16	846.57	2.75	843.82					6.18	3.43		840.39	840.39	3.43
BMW17	842.03	2.63	839.4					4.31	1.68		837.72	837.72	1.68

APPENDIX C

SOIL GRAIN SIZE ANALYSES AND SOIL MOISTURE ANALYSES DATA

SOIL GRAIN SIZE ANALYSES
USING #4, #10, #100, #150, #200 MESH SCREENS

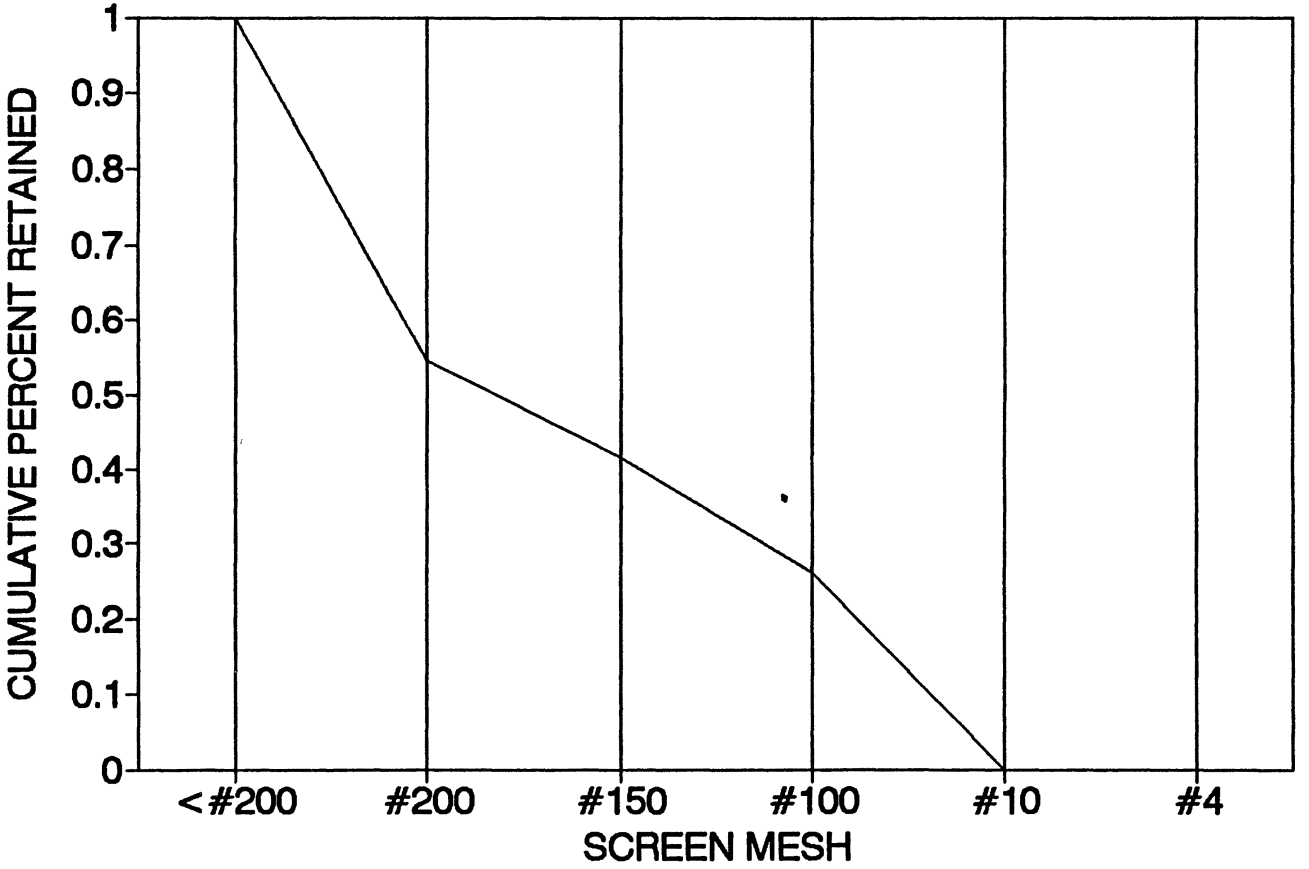
WEIGHT OF SOIL RETAINED (grams) SCREEN MESH				0			WEIGHT BEFORE	TOTAL WEIGHT AFTER	PERCENT RECOVERED
SVP1	<#200	#200	#150	#100	#10	#4	SCREENING	SCREENING	
0-1'	50.1	14 4	17.2	28 8	0	0	112.9	110.5	0.979
1-2'	71.9	16 4	15 4	14 8	0	0	120.4	118 5	0.984
2-3'	83.8	19.2	8.2	26 5	0	0	138.8	137.7	0.992
SVP2	<#200	#200	#150	#100	#10	#4			
0-1	56.4	14 6	19 6	47 0	0	0	139.1	137.6	0 989
1-2	57.9	19.3	18.5	47.2	0	0	144.8	142.9	0.987
2-3	50.3	16 9	21 5	54.8	0	0	147.0	143.5	0.976
SVP4	<#200	#200	#150	#100	#10	#4			
0-1	48 4	13.2	14.3	31.0	0	0	110.0	106.9	0.972
1-2	68.8	18.1	15.9	54.9	0	0	160.4	157.7	0.983
2-3	58.6	12.7	15.3	27 4	0	0	116.7	114.0	0.977

PERCENT RETAINED

SVP1						
0-1	0.4534	0.1303	0.1557	0.2606	0	0
CUM.	1.0000	0.5466	0.4163	0.2606	0	0
1-2	0.6068	0.1384	0.13	0.1249	0	0
CUM.	1.0000	0.3932	0.2549	0.1249	0	0
2-3	0.6086	0.1394	0.0595	0.1924	0	0
CUM.	1.0000	0.3914	0.252	0.1924	0	0
SVP2						
0-1	0.409884	0.1061	0.1424	0.3416	0	0
CUM.	1.0000	0.5901	0.484	0.3416	0	0
1-2	0.405178	0.1351	0.1295	0.3303	0	0
CUM	1.0000	0.5948	0 4598	0.3303	0	0
2-3	0.350523	0.1178	0.1498	0.3819	0	0
CUM	1.0000	0.6495	0.5317	0.3819	0	0
SVP4						
0-1	0.45276	0.1235	0.1338	0.29	0	0
CUM.	1.0000	0.5472	0.4238	0.29	0	0
1-2	0.436271	0.1148	0.1008	0.3481	0	0
CUM.	1.0000	0.5637	0.449	0.3481	0	0
2-3	0.514035	0.1114	0.1342	0.2404	0	0
CUM.	1.0000	0.486	0.3746	0.2404	0	0

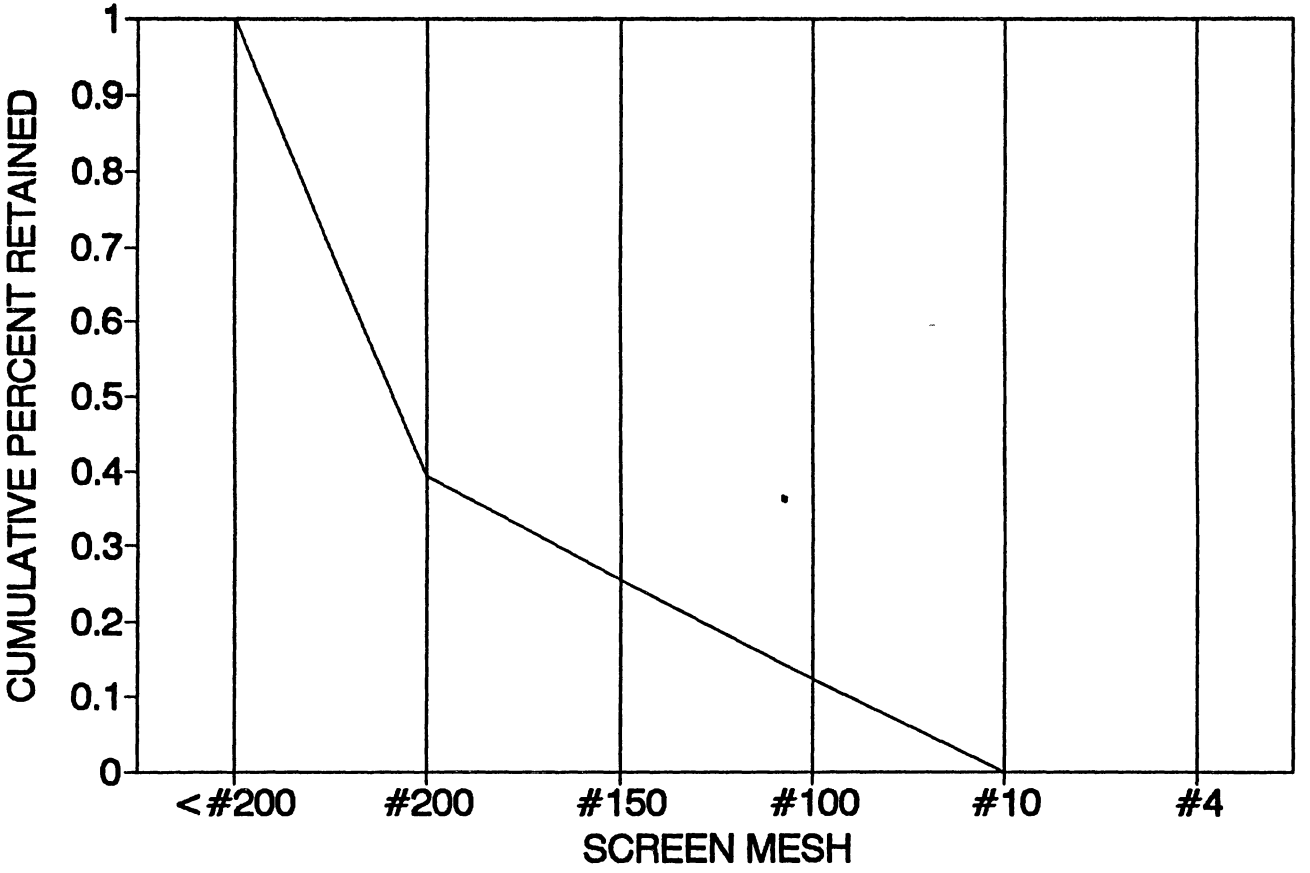
SVP1

0 to 1 FOOT



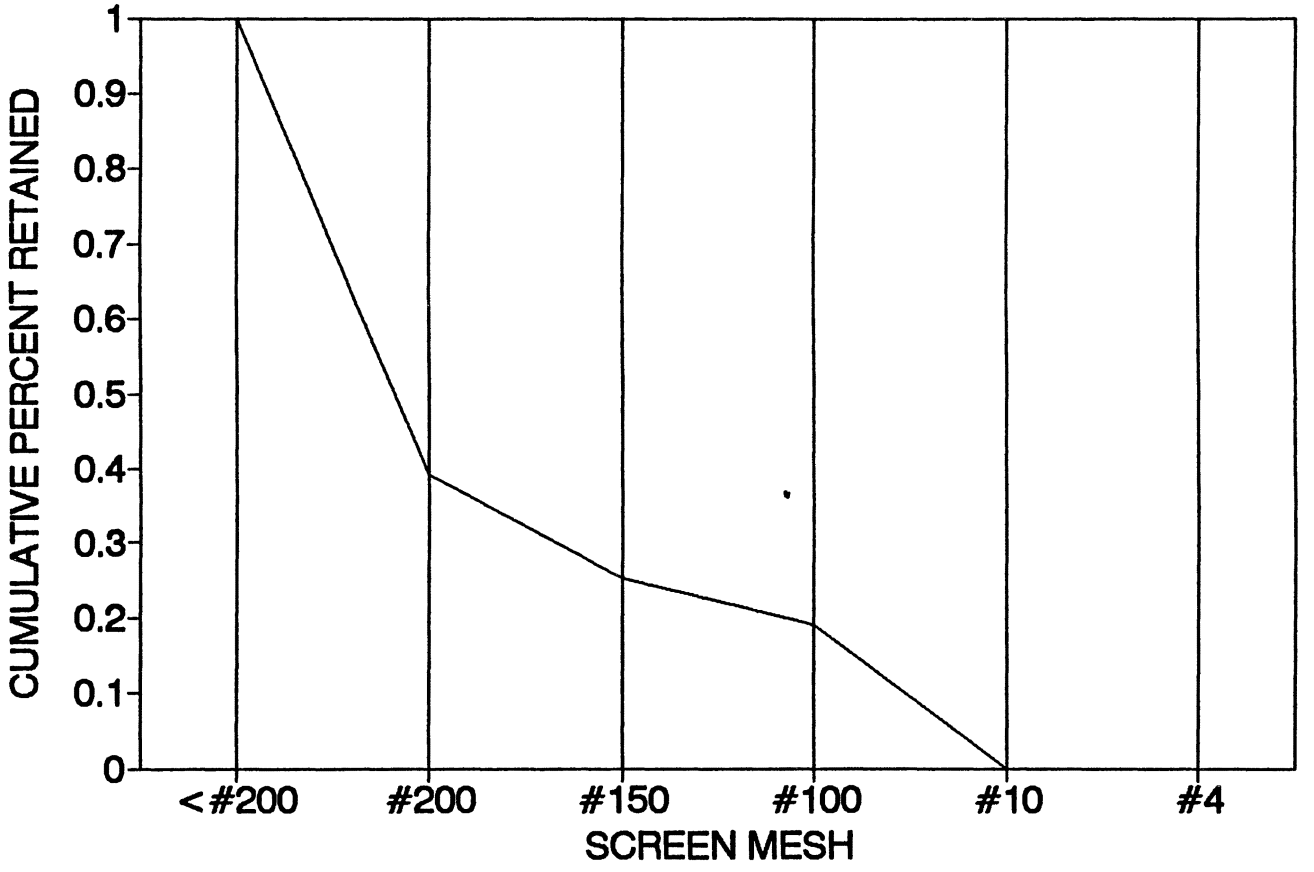
SVP1

1 to 2 FEET



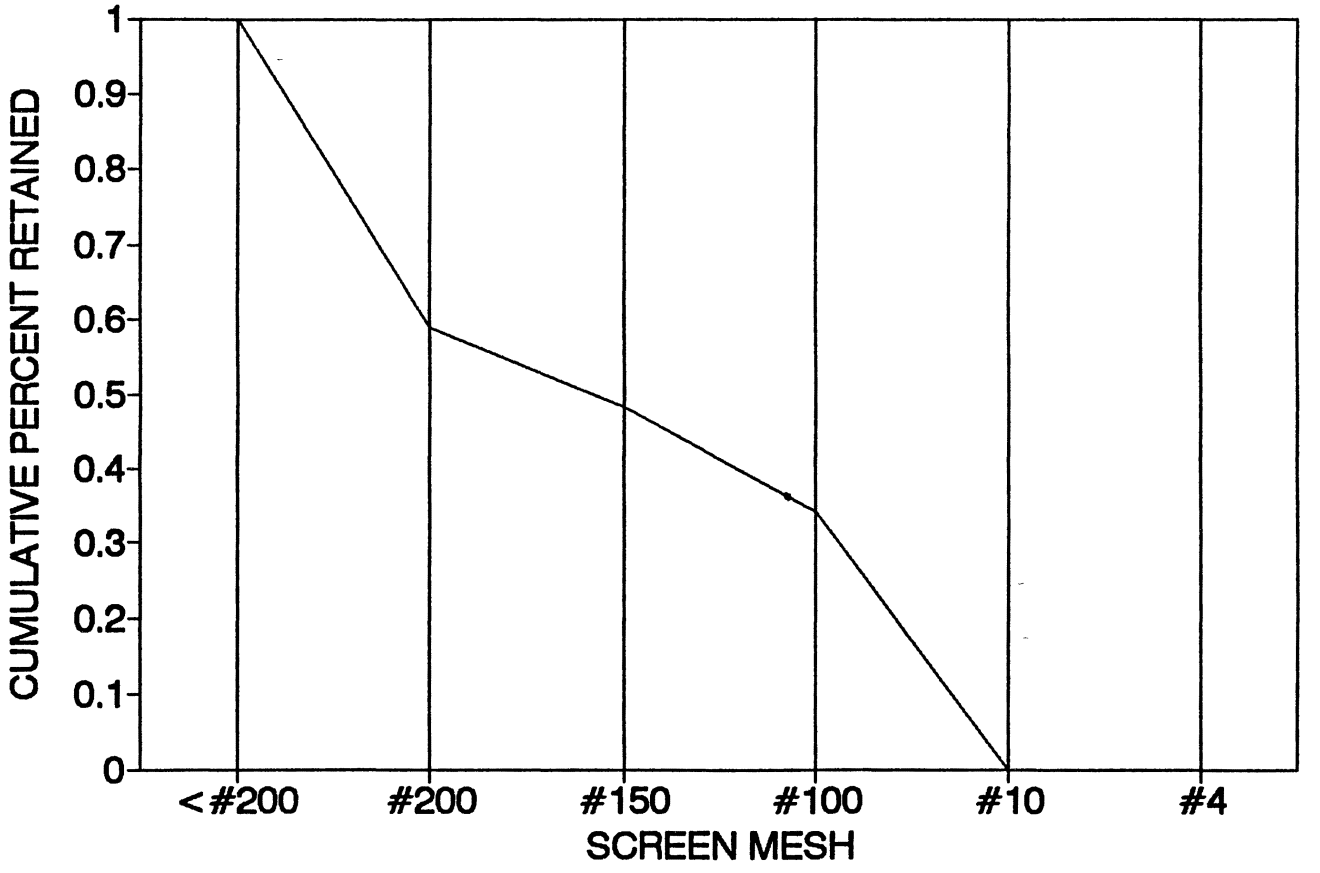
SVP1

2 to 3 FEET



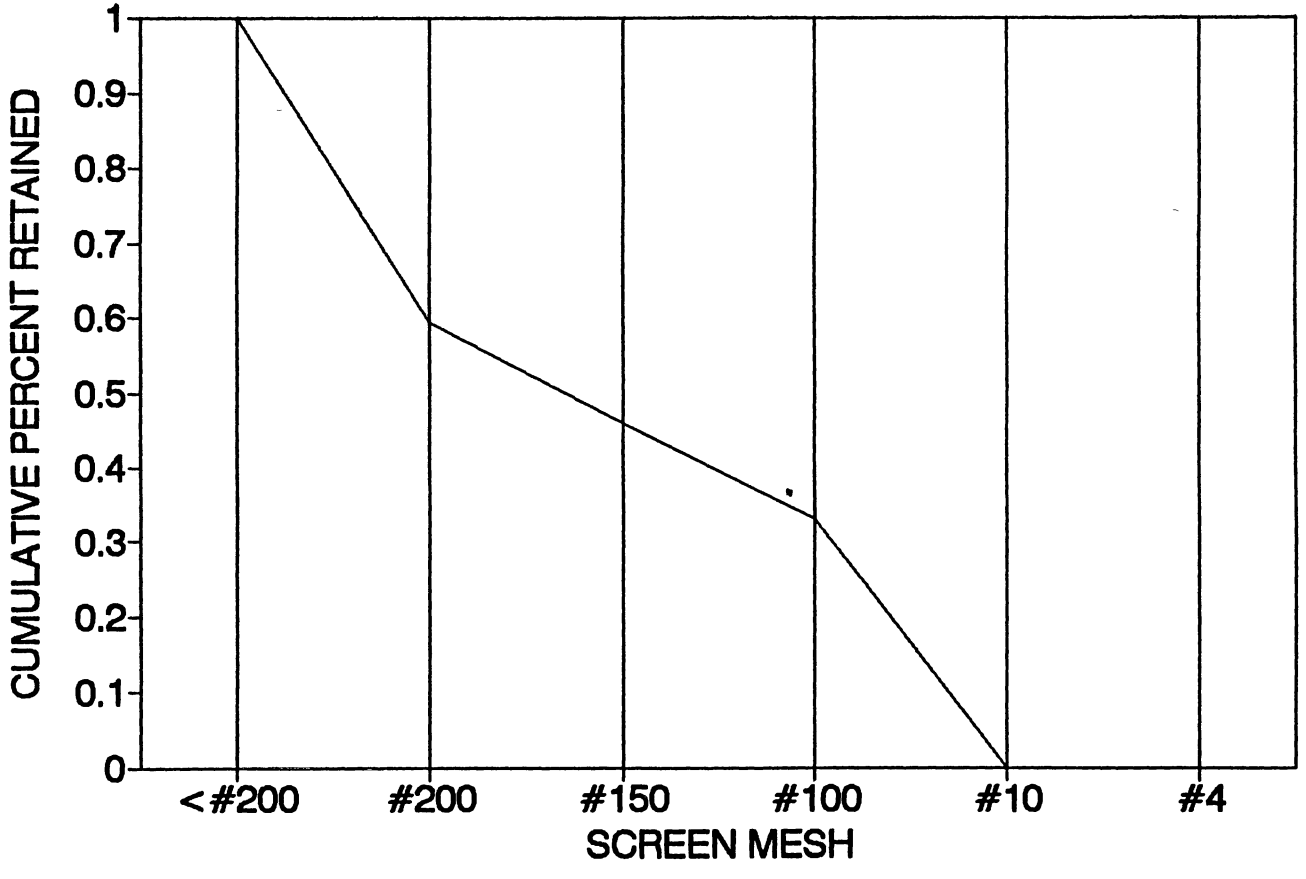
SVP2

0 to 1 FOOT



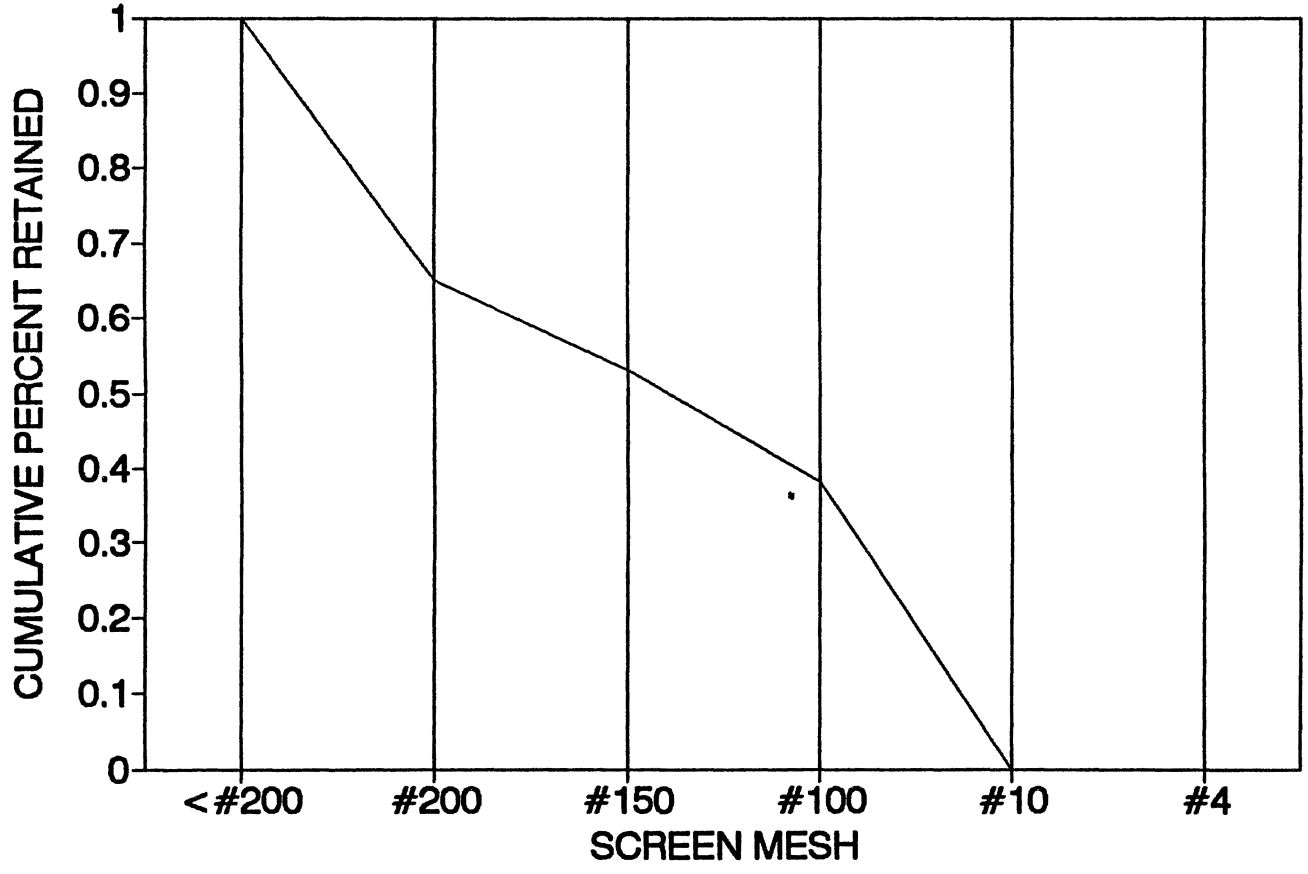
SVP2

1 to 2 FEET



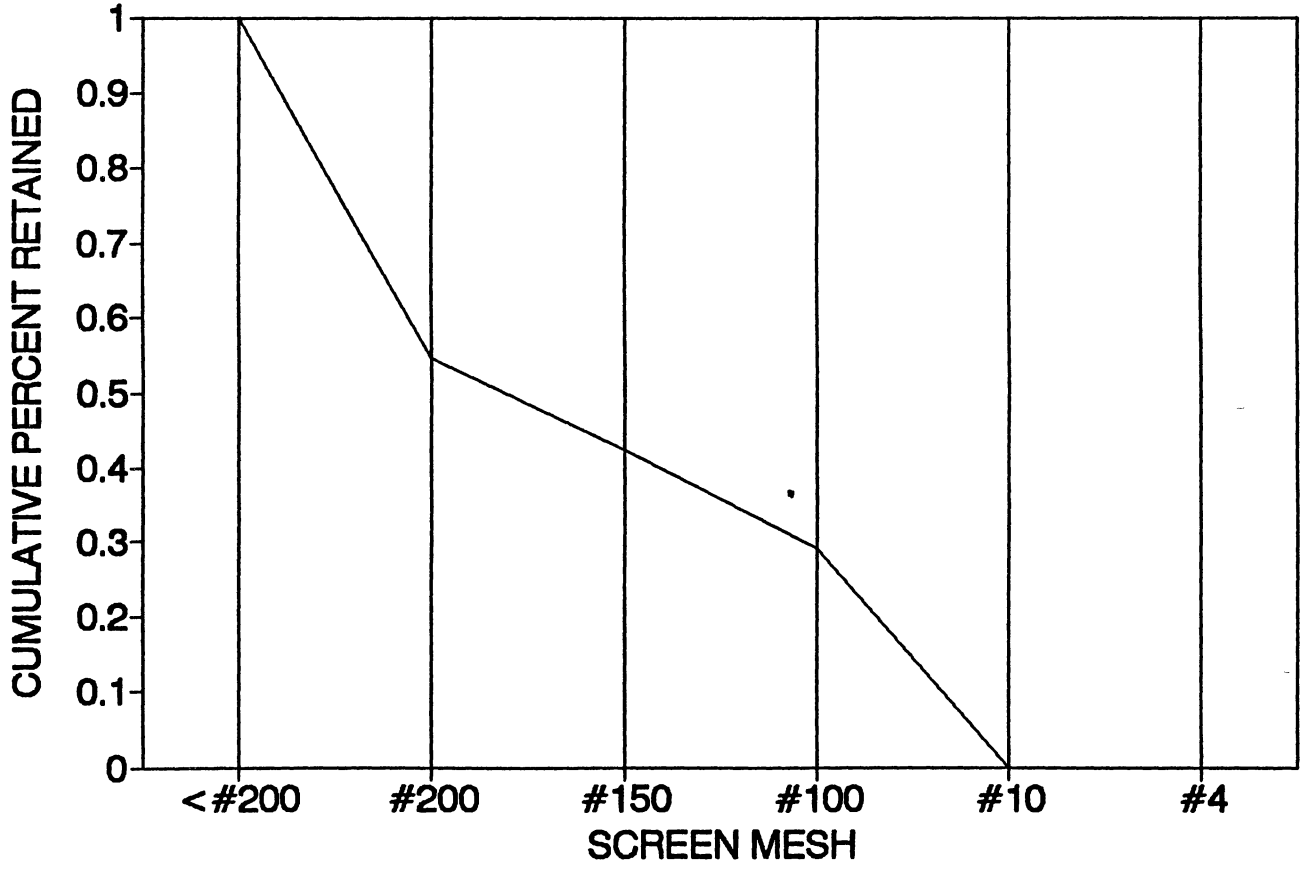
SVP2

2 to 3 FEET



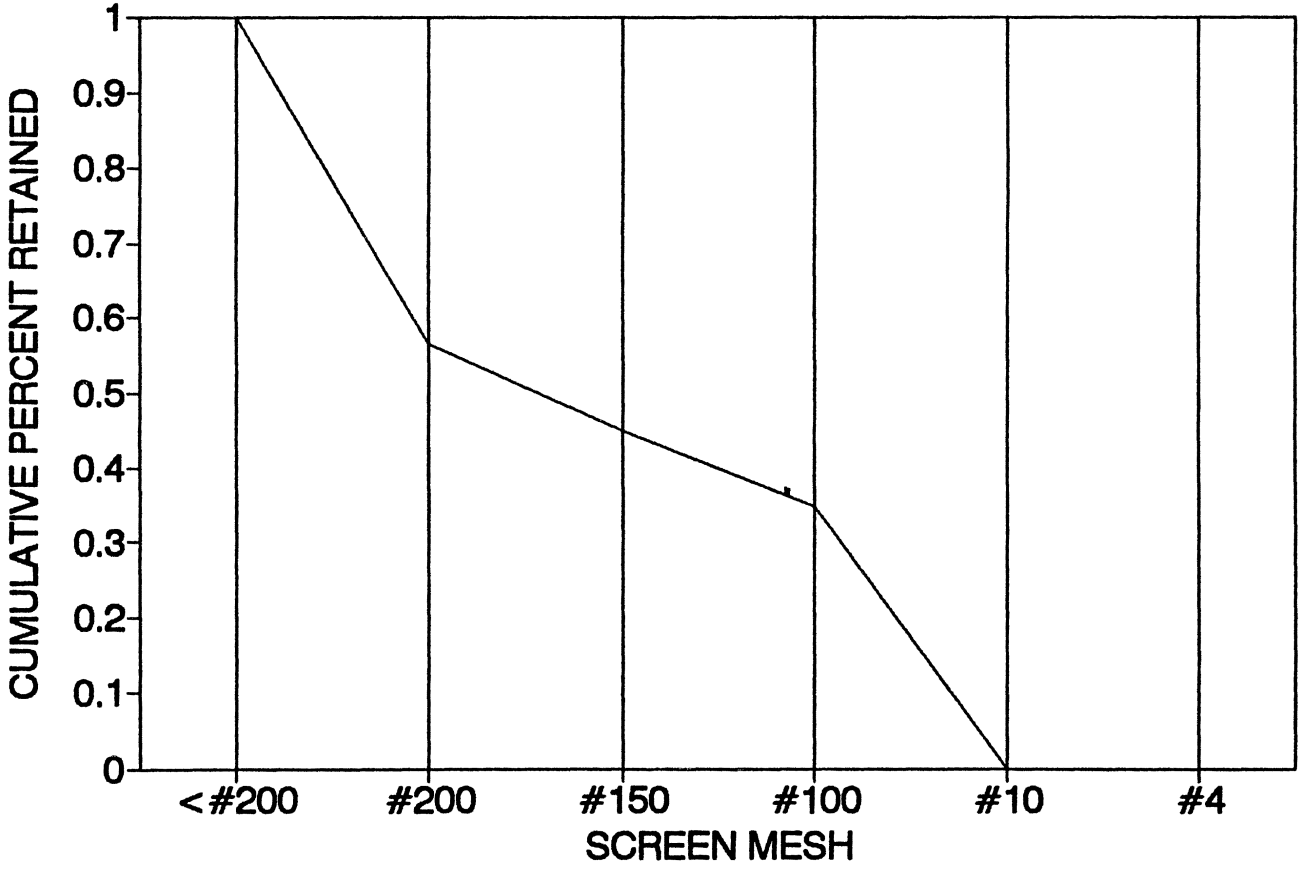
SVP4

0 to 1 FOOT



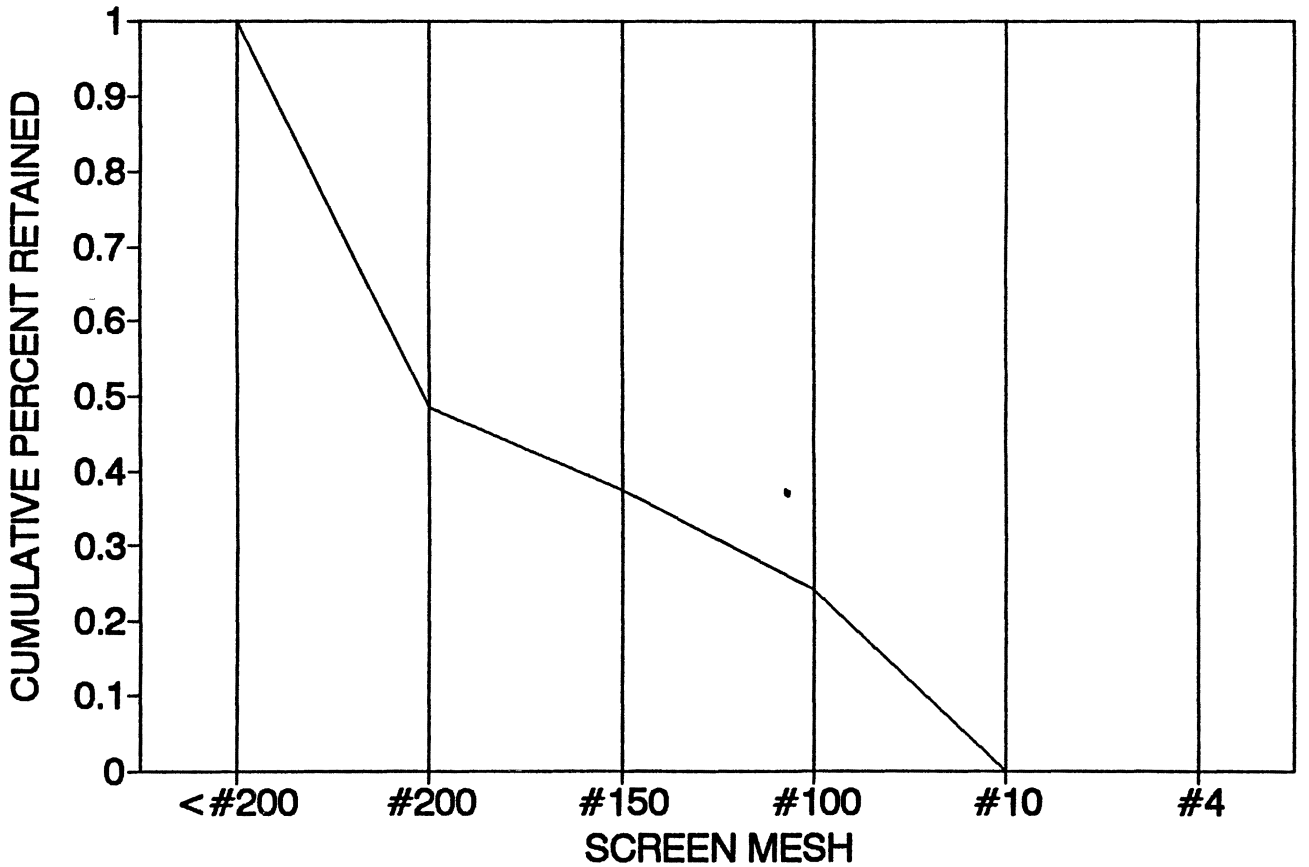
SVP4

1 to 2 FEET



SVP4

2 to 3 FEET



SOIL MOISTURE ANALYSES DATA

FOUNDATION DEPARTMENT

PROJECT NO
Job TIM BENT

Date Drilled 6-26-91
By
Branch

Boring No / Depth Range	SVP-1	SVP-2 & 3	SVP-4			
Tare Number						
Tare Weight						
Wet Soil + Tare	150.3	139.5	166.4			
Dry Soil + Tare	131.4	120.5	140.1			
Weight of Water	18.9	19.0	26.3			
% Moisture Content	12.6	13.6	15.8			
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

FOUNDATION DEPARTMENT

PROJECT NO
Job. TIM BENT

Date Drilled 6-14-91
By
Branch

Boring No / Depth Range	SVP-1	SVP-2 & 3	SVP-4			
Tare Number						
Tare Weight						
Wet Soil + Tare	136.9	175.5	158.9			
Dry Soil + Tare	120.2	152.4	136.8			
Weight of Water	16.7	23.1	22.1			
% Moisture Content	13.9	15.2	16.2			
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

PROJECT NO G-449
Job. TIM BENT

FOUNDATION DEPARTMENT

Date Drilled 4-30-91
By
Branch

Boring No / Depth Range	SVP-1	SVP-2	SVP-3	SVP-4		
Tare Number						
Tare Weight						
Wet Soil + Tare	175.2	168.5	124.4	132.6		
Dry Soil + Tare	155.6	146.9	107.4	113.5		
Weight of Water	19.6	21.6	17.0	19.1		
% Moisture Content	12.6	14.7	15.8	16.8		
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

PROJECT NO G-449G
Job. TIM BENT

FOUNDATION DEPARTMENT

Date Drilled 4-16-91
By
Branch "G" Samplers"

Boring No / Depth Range	SVP1	SVP2	SVP3	SVP4		
Tare Number						
Tare Weight						
Wet Soil + Tare	151.3	131.6	131.2	130.2		
Dry Soil + Tare	132.9	115.2	112.2	113.6		
Weight of Water	18.4	16.4	19.0	16.6		
% Moisture Content	14.2	14.2	16.9	14.6		
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

PROJECT NO G-449
Job TIM BENT

FOUNDATION DEPARTMENT

Date Drilled 5-22-a
By
Branch

Boring No / Depth Range	SVP 1	SVP 2	SVP 3	SVP 4		
Tare Number						
Tare Weight						
Wet Soil + ~~Tare~~	244.8	295.6	249.4	231.3		
Dry Soil + ~~Tare~~	215.9	256.9	214.7	198.8		
Weight of Water	28.9	38.7	34.7	32.5		
% Moisture Content	13.4	15.1	16.2	16.3		
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

PROJECT NO G-449 **FOUNDATION DEPARTMENT** Date Drilled 3-1+-71
Job. TIM BENT By
Branch

Boring No / Depth Range	SVP1	SVP2	SVP3	SVP4		
Tare Number						
Tare Weight						
Wet Soil + Tare	125.5	138.8	125.5	107.2		
Dry Soil + Tare	109.8	121 3	107.6	93.7		
Weight of Water						
% Moisture Content	14 3	14.4	16 6	14.4		
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

PROJECT NO G.449 F
Job. TIM BENT

FOUNDATION DEPARTMENT

Date Drilled 3/8/91
By
Branch "F" samples

Boring No / Depth Range	SVP 1	SVP 2	SVP 3	SVP 4		
Tare Number						
Tare Weight						
Wet Soil + Tare	139.6	125.9	158.9	181.1		
Dry Soil + Tare	123.4	111.3	137.6	158.1		
Weight of Water	16.2	14.6	21.3	23.0		
% Moisture Content	13.1	13.1	15.5	14.5		
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

PROJECT NO G-449E
Job: SVP E

FOUNDATION DEPARTMENT

Date Drilled 2/28/91
By
Branch. "E" samples

Boring No / Depth Range	SVP1	SVP2	SVP3	SVP4		
Tare Number						
Tare Weight						
Wet Soil + ~~Tare~~	122.0	124.9	115.6	117.5		
Dry Soil + ~~Tare~~	107.7	111.7	99.0	100.5		
Weight of Water	14.3	13.2	16.6	17.0		
% Moisture Content	13.3	11.8	16.8	16.9		
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

data entered

PROJECT NO G-449 D
Job. TIM BENT.

FOUNDATION DEPARTMENT

Date Drilled 2/22/91
By
Branch "D" samples

Boring No Depth Range	SV P3D	SV P4D				
Tare Number						
Tare Weight						
Wet Soil + ~~Tare~~	89.8	93.6				
Dry Soil + ~~Tare~~	77.2	82.0				
Weight of Water						
%, Moisture Content	16.3	14.2				
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

data entered

PROJECT NO Job: TIM BENT G-4449C

FOUNDATION DEPARTMENT

Date Drilled 2/18/91
By "C" samples
Branch

Boring No / Depth Range	SVP1C	SVP2C	SVP3C	SVP4C	SVP1D	SVP2D
Tare Number						
Tare Weight						
Wet Soil + Tare	103.6	105.3	102.8	101.8	82.1	80.4
Dry Soil + Tare	91.3	91.8	89.3	89.7	73.0	70.8
Weight of Water						
%, Moisture Content	13.5	14.7	15.1	13.5	12.5	13.6
Pocket Penetration						
Soil Description						
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

data entered

PROJECT NO 6449B
Job. TIM BENT

FOUNDATION DEPARTMENT

Date Drilled 2/18/91
By
Branch

Boring No	SVP1	SVP2	SVP3	SVP4		
Depth Range						
Tare Number BOTTLE	P1	P2	P3	P4		
Tare Weight weigh back dry	13045	13005	13046	13056		
Wet Soil + Tare	337.75	339.00	314 80	335 75		
Dry Soil + Tare	312.13	311.53	286.17	302.80		
Weight of Water	25 62	27 47	26 63	32 95		
% VOLATILES %, Moisture Content	4.1	15.1	16.9	19.1		
DS Pocket Penetration	18168	18146	15771	172.24		
Soil Description	GRAY BROWN VF SAND SILT & CLAY W/ ODOR OF HYDROCARBON	LIGHT BROWN CLAYEY VF SND & SILT W/ODOR OF HYDROCARBON	MED BROWN SILTY CLAY W/NO APPARANT ODOR OF HYDROCARBON	BROWN SILTY CLAY W/GRAY SANDY MOTTLES AND ODOR OF HYDROCARBON		
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

data entered

PROJECT NO 6-447A **FOUNDATION DEPARTMENT** Date Drilled 1/30/91
Job By
Branch

Boring No / Depth Range	SV P1	SV P2	SV P3			
Tare Number	—	—	—			
Tare Weight	-0-	-0-	-0-			
Wet Soil + ~~Tare~~	161.8	154.3	139.4			
Dry Soil + ~~Tare~~	140.6	135.2	122.4			
Weight of Water						
% Moisture Content	15.1	14.1	13.9			
Pocket Penetration						
Soil Description	DK Brown silty sandy clay (Hydrocarbon Contamination)	Brown silty clayey sand Hydrocarbon odor.	DK Brown silty clayey sand			
Wt Sample						
Wt Coated						
Wt in Water						
Wt Paraffin						
Coated Volume						
Sample Volume						
Natural Gravity						
Natural Density						
Dry Gravity						
Dry Density						
Property of the Soil						
Approx P I						

APPENDIX D

PORTABLE GC AND LABORATORY ANALYTICAL DATA, SORTED BY DATE

[redacted]

[redacted]

36

Thursday June 27, 1991

Gas sample bags from Wynnewood (Tim's thesis)

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
310		BTEX Std					
311	15	BTEX Std	B	27	10.81 ppm	100 ml	
			T	38	10.89		
			E	53	11.24		
			o-X	69	11.44		
312	15	BMW-10	went off scale			100 ml	
313	15	BLANK	No peaks			100 ml	
314	15	BMW-10	T	37	90.53	100 ml	90%
			E	55	39.44		10%
315	15	BMW-10	T	37	33.86	100 ml	90%
							10%
316	15	BMW-10	T	36	91.55	100 ml	90%
			E	55	56.27		10%
						BMW10 AVG.	
317	15	BTEX-Std	B		10.81	B = ND	
		Bad Calibration	T		10.89	T = 819	
			E		11.24	E = 431	
			X		11.44	X = ND	
318	15	BTEX-Std					
		Bad Calibration					

[redacted]

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37

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
319	15	BTEX Std	B	26	10.81 ppm	100 ml	
			T	36	10.89		
			E	51	11.24		
			o-X	66	11.44		
320	15	BMW 22	went off scale			100 ml	
321	15	BMW 22	went off scale			100 ml	90% air 10% sample
322	15	BMW 22	went off scale			100 ml	95% air 10% sample
323	15	BLANK	T	36	Did not call		
324	15	BTEX Std					
325	15	BTEX Std	B	26	10.81	100 ml	
			T	36	10.89		
			E	50	11.24		
			X	65	11.44		
326	15	BMW 27	T	36	1.88	100 ml	90% air 10% sample
			E	53	2.75		
327	15	BMW-17	–			100 ml	
			Bad injection				
328	15	BMW-17	T	36	3.38	100 ml	
			E	53	3.56		
329	15	BMW-17	T	36	3.14	100 ml	
			E	53	2.84		

BMW-17 AVG: B ND
T 252
E 558

[redacted]

[redacted]

38

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
330	15	BTEX Std	B	27	10.81 ppm	100ml	
			T	37	10.89		
			E	51	11.24		
			O-X	66	11.44		
331	15	BMW-11	B	Did not call trc.		100ml	40% air
			T	37	5.01		10% sample
			E	53	3.25		
332	15	BMW-11	~~B~~ T	37	15.53	100ml	
			~~T~~ E	54	18.31		
333	15	BMW-11	B	Did not call trc.		100ml	
AVG	B 0.5	4.5	T	37	19.33		
BMW11	T 13.28	120	E	54	19.65		
	E 13.77	124	X	Did not call			
	X 0.5	4.5					
	14.1						
334	15	BTEX Std				100ml	
		Bad calib.					
335	15	BTEX Std	B	27	10.81	100ml	
			T	36	10.89		
			E	50	11.24		
			X	65	11.44		
→ 336		SVP 2OH	B	27	31.48	100ml	50% air
			T	36	39.77		50% sample
			E	54	26.80		
			X	66	10.55		

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	RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
good →	337	15	SVP1.0H	B	27	36.90 ppm	100 ml	50% air
SVP1 avg. OH	B 68		TOTAL BTEX	T	36	59.99		50% sample
	T 190		253	E	54	34.96		
	E 62			X	66	12.29		
	X 23							
	338	15	SVP2 0H	went off scale			100 ml	50% air
								50% sampl
	339	15	SVP2.0H	B	26	29.33 ppm	100 ml	90% air
				T	36	121.00		10% samp
				E	54	129.03		
				X	66	37.06		
				Unk	79	11.61		
				Unk	105	4.98		
good →	340	15	SVP2.0H	B	27	29.52	100 ml	90% air
				T	36	97.30		10% sam
				E	54	85.72		
				X	65	23.66		
				Unk	79	2.81		
	341	15	SVP2.0H needle clogged mechally					
air sample good →	342	15	SVP2.0H	B	27	23.83		90% air
				T	36	82.16		10% samp
SVP2.0H AVG.	BTEX 248			E	53	83.55		
	T 903			X	66	16.12		
	E 894			Unk	79	3.02		
	X 231							
	Unk (79 sec) 52							
	Unk (105 sec) 45							

Signature Roy K Wichmann Date 6/27/91

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RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE
343	15	BTEX Std	B	26	10.81	100ml
			T	36	12.89	
			E	51	11.24	
			O-X	65	11.44	
344	15	BLANK	B	Did not call		100ml
			T	36	4.41	
			E	53	4.52	
			O-X	65	1.37	
345	15	BLANK	T	36	0.68	100ml
			E	53	2.21	
346	15	BLANK	T	36	0.53	100ml
			E	53	1.06	
347	15	BLANK	T	Did not call		100ml
			E	53	0.79	
~~348~~	~~"~~					
348	15	BLANK	T	Did not call		100ml
349	15	STEX Std	B	26	10.81	100ml
			T	36	10.89	
			E	50	11.24	
			X	64	11.44	
350	15	SVP4 OH	B	26	Did not call	100ml 90% air 10% sample
			T	36	31.95	
			E	54	21.66	
			OX	65	6.32	

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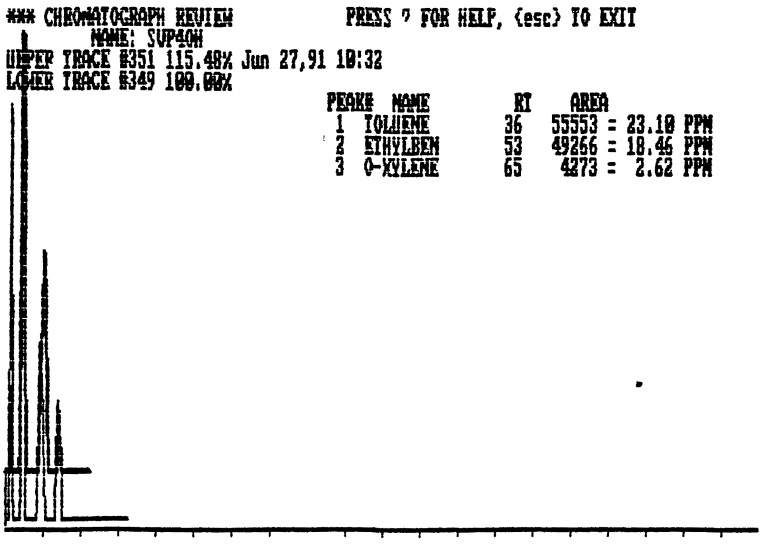
41

RUN	GAIN	SAMPLE ID	PEAK	RT	conc	SAMPLE SIZE	
go → 351	15	SVP4OH	B	Did not call	<1 ppm	100 ml	90% air 10% sample
			T	36	23.10		
			E	53	18.46		
			o-X	65	2.67		
good → 352	15	SVP4OH	B	Did not call	<1	100 ml	90% air, 10% sample
SVP4OH AVG.	B	40.5	T	36	22.64		
	T	233	E	53	16.18		
	E	169	o-X	65	Did not call		
	X	28					
353	15	BLANK	T	36	2.95	100 ml	
354	15	BLANK	T	36	1.68	100 ml	
355	15	BLANK	T	Did not call			
356	15	BTEX Std	B	27	10.81	50 ml	
			T	36	10.89		
			E	50	11.24		
			X	65	11.44		
357	15	BMW 22	B	Did not call		50 ml	90% air 10% sample
→			T	36	34.61		
good			E	53	55.27		
			o-X	65	20.23		
358	15	BMW 22	B	Did not call		50 ml	90% air 10% sample
			T	36	36.45		
			E	53	24.58		
359	15	BMW 22	B	Did not call			
		Bad track	T				

Signature [redacted] 6/27/01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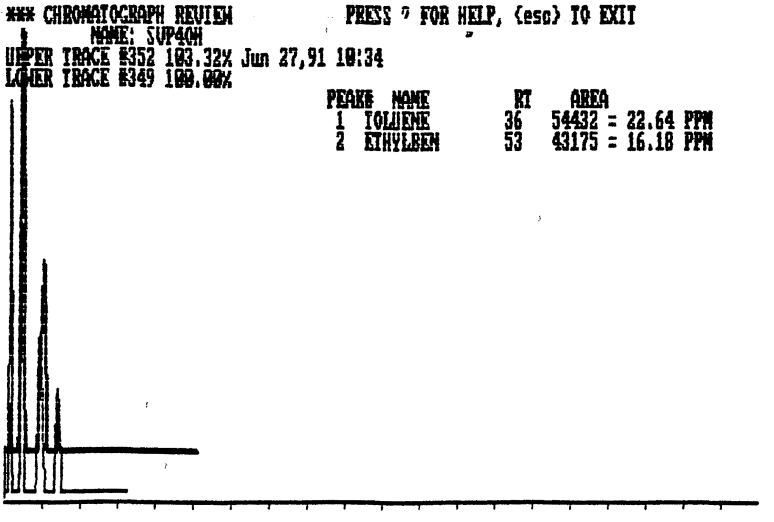
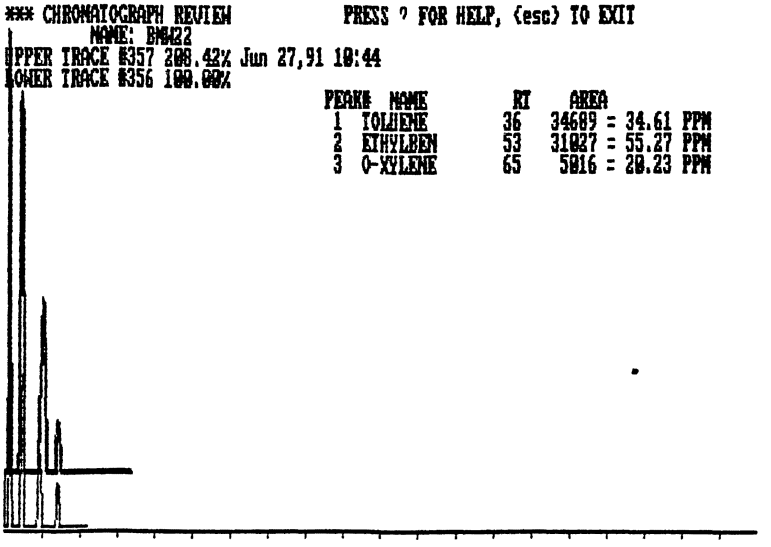
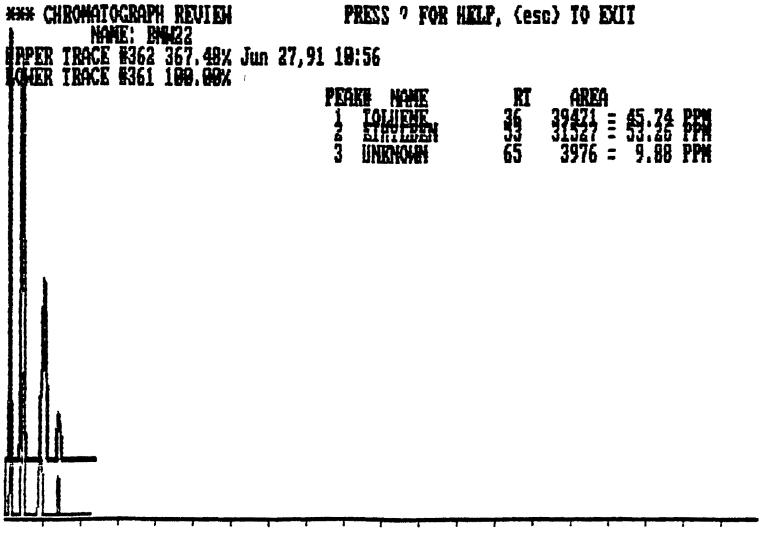
NAME: SVP4QH
UPPER TRACE #351 115.48% Jun 27,91 10:32
LOWER TRACE #349 100.00%
PEAK# NAME RT AREA
1 TOLUENE 36 55553 = 23.10 PPM
2 ETHYLBEN 53 49266 = 18.46 PPM
3 O-XYLENE 65 4273 = 2.62 PPM

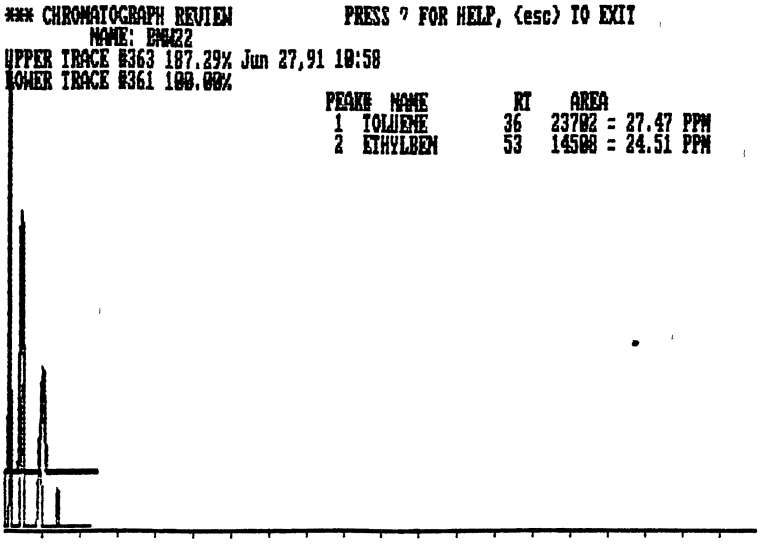

*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: SVP4QH
UPPER TRACE #352 103.32% Jun 27,91 10:34
LOWER TRACE #349 100.00%
PEAK# NAME RT AREA
1 TOLUENE 36 54432 = 22.64 PPM
2 ETHYLBEN 53 43175 = 16.18 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: BM422
UPPER TRACE #357 208.42% Jun 27,91 10:44
LOWER TRACE #356 100.00%
PEAK# NAME RT AREA
1 TOLUENE 36 34689 = 34.61 PPM
2 ETHYLBEN 53 31027 = 55.27 PPM
3 O-XYLENE 65 5016 = 20.23 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: BM422
UPPER TRACE #362 367.48% Jun 27,91 10:56
LOWER TRACE #361 100.00%
PEAK# NAME RT AREA
1 TOLUENE 36 39421 = 45.74 PPM
2 ETHYLBEN 53 31527 = 53.26 PPM
3 UNKNOWN 65 3976 = 9.88 PPM

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
360	15	BMW.22				50ml	90% air 10% sample
		Bad run clogged syringe?					
361	15	BTEX Std	B	27	10.81	50ml	90% air 10% sample
			T	36	10.89		
			E	56	11.24		
			X	Did not call			
good ⇒ 362	15	BMW 22	B	Did not call		50ml	90% air
			T	36	45.74		10% sample
			E	53	53.26		
			X	65	9.88		
363	15	BMW 22	B	Did not call		50ml	90% air
			T	36	27.47		10% sample
			E	53	24.51		
364	15	BMW 22	B	Did not call		50ml	90% air
			T	Did not call			10% sample
		B.H.W22 avg	B	= 10.81		=	~~97~~
			T	= 36.07		=	325
			E	= ~~57.62~~	39.41	=	355
			X	= 15.06		=	136
				.111			

Signature _____ Date _____


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: BMW22
UPPER TRACE #363 187.29% Jun 27,91 10:58
LOWER TRACE #361 100.00%
PEAK# NAME RT AREA
1 TOLUENE 36 23702 = 27.47 PPM
2 ETHYLBEN 53 14508 = 24.51 PPM

[redacted]

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RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
319	15	BTEX Std	B	24	10.81 ppm	100 ml	
			T	36	10.89		
			E	51	11.24		
			o-X	66	11.44		
320	15	BMW 22	went off scale			100 ml	
321	15	BMW 22	went off scale			100 ml	90% air 10% sample
322	15	BMW 22	went off scale			100 ml	95% air 10% sample
323	15	BLANK	T	36	Did not call		
324	15	BTEX Std					
325	15	BTEX Std	B	24	10.81	100 ml	
			T	36	10.89		
			E	50	11.24		
			X	65	11.44		
326	15	BMW #7	T	36	1.88	100 ml	90% air 10% sample
			E	53	2.75		
327	15	BMW-17	– Bad injection			100 ml	
328	15	BMW-17	T	36	3.38	100 ml	
			E	53	3.56		
329	15	BMW-17	T	36	3.14	100 ml	
			E	53	2.84		

BMW17 Ave. B ND
T 252
E 58

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Fax 214-669 3575

[redacted]
ATTN TIM BENT

SAMPLE ID BMW-1

DATE RECEIVED 06/17/91

DATE ANALYZED 06/17/91
DATE REPORTED 06/20/91
REPORT NUMBER 0636-1

BTEX

PARAMETERS	METHOD	DETECTION LIMIT ug/l	RESULTS ug/l	ANALYST
Benzene	8020	5	8	GK
Ethyl benzene	8020	5	<5	GK
Toluene	8020	5	82	GK
Xylenes	8020	5	1977	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES INC

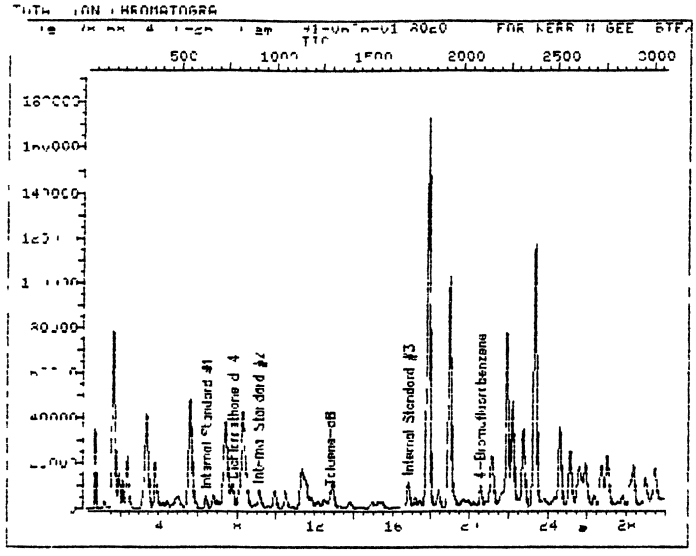
QUANT REPORT

Operator ID: GELPKE Quant Rev: 0 Quant Time: 910617 _ _ 1_
Output File: 09065 WD Injected at: 910_1 _ _
Data File: 09065 D4 Dilution Factor: 1.000 0
Name: 91-0436-01 8020
Type: [redacted] BIE

ID File: IDV0A9 WT
Title: Daily Cal via Single Point at 50 ug/L 30M DE-5_4
Last Calibration: 910617 15 _0

	Compound	RT	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	8 42	128 M	5961	50.00	UG/L	91
2)	ACROLEIN	3 80	56 V	62_94	4745.47	UG/_	1_6
3)	ACRYLONITRILE	7 51	53 V	5240	103.1_	UG/L	1_0
4)	Chloromethane	1 04	50 M	6397	12_.47	UG/L	9_
10)	Acetone	3 33	43 V	143071	3211.35	UG/L	1_0
1c)	1,2-Dichloroethane-d4 *****	7 77	65 V	13514	61.70	UG/L	9_
1o)	*1,4-Difluorobenzene	9 06	114 V	27497	50.00	UG/L	10_
21)	2-Butanone (MEK	39	43 V	91949	1052.86	UG/_	9_
22)	Vinyl Acetate	3 80	43 V	7243	243.57	UG/L	7_
23)	Benzene	7 82	78 M	3329	9.69	UG/L	1_
31)	*Chlorobenzene-d5	1c 78	117 V*	17169	50.00	UG/L	93
3_	4-Methyl-2-Pentanone (MIBK)	12 87	43 V	1c01	11.39	UG/L	9_
_	Toluene	12 92	92 V	2_34_	82.49	UG/L	9_
49	Toluene-d8 ********	12 75	98 V	29181	52.79	UG/L	81
41)	Ethyl Benzene	1_ 29	106 V	237196	1469.66	UG/L	7_
42)	XYLENE (TOTAL)	1_ 29	106 V	373907M	1926.95	UG/_	9_
44)	Bromofluorobenzene ********	20 57	95 V	16307	62.83	UG/L	88

* Compound is (S)



Data File V8068 V4 Quant Output File V8068 V5
Misc [redacted] BTEX

d File IDVJAY QT
Title Daily Cal via Single Point at 50 ug L 30M DB-624
Last calibration 91U-17 18 26

Operator ID GEOFGE
Quant Time 91U617 17 16
Injected at 91U617 22 45

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[redacted]
ATTN TIM BENT

SAMPLE ID BMW-3

DATE RECEIVED 06/17/91

DATE ANALYZED 06/17/91
DATE REPORTED 06/20/91
REPORT NUMBER 0636-6

BTEX

PARAMETERS	METHOD	DETECTION LIMIT ug/l	RESULTS ug/l	ANALYST
Benzene	8020	5	<5	GK
Ethyl benzene	8020	5	<5	GK
Toluene	8020	5	<5	GK
Xylenes	8020	5	<5	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC

GM

D#91/0. 0636-6B

QUANT REPORT

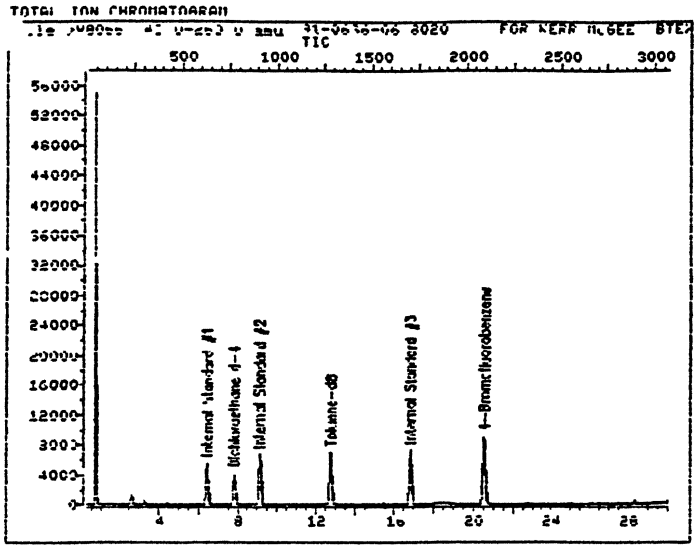
Operator ID. GEORGE Quant Rev 6 Quant Time 910617 2[illegible]
Output File [illegible]U8066 QO Injected at 910617 21 38
Data File [illegible]U8066 U4 Dilution Factor 1 00000
Name 91-0636-06 8020
Misc [redacted] BTEX

ID File: IDU0A9[illegible]QT
Title Daily Cal via Single Point at 50 ug/L 30M UB-624
Last Calibration 910617 18 26

	Compound	R T.	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 40	128 0	5535	50.00	UG/L	95
2)	ACROLEIN	4 42	56 0	114	11.10	UG/L	100
8)	Methylene Chloride	3 29	84 0	724	3 99	UG L	96
9)	Trichlorofluoromethane	2.57	101 0	3145	3 99	UG/L	8[illegible]
10)	Acetone	3 21	43.0	321	7 76	UG/L	100
16)	1,2-Dichloroethane-d4 *****	7.77	65 0	12764	52.67	UG L	9[illegible]
18)	*1,4-Difluorobenzene	9.06	114 0	22580	50 00	UG/L	100
22)	Vinyl Acetate	3.26	43 0	128	4 49	UG/L	80
30)	Benzene	7.80	78 0	238	50	UG/L	100
33)	*Chlorobenzene-d5	16 76	117 0	19905	50.00	UG/L	92
39)	Toluene-d8 ********	14.75	98 0	21312	48 00	UG/L	9[illegible]
44)	Bromofluorobenzene ********	20 51	95 0	16084	53 47	UG/L	8[illegible]

* Compound is ISTD

No 8020 Compounds
Napm



Data File >V8066 .U4 Quant Output File ^V8066 QO
Name 91-1636-06 8020
Misc [redacted] BTEX

Id File IDV0A9 .QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910617 18:26

Operator ID GEORGE
Quant Time 910617 22 08
Injected at 910617 21 38

END

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[redacted]

ATTN: TIM BENT

SAMPLE ID: BMW-8

DATE RECEIVED. 06/17/91

DATE ANALYZED: 06/17/91
DATE REPORTED. 06/20/91
REPORT NUMBER. 0636-5

BTEX

PARAMETERS	METHOD	DETECTION LIMIT ug/l	RESULTS ug/l	ANALYST
Benzene	8020	5	10720	GK
Ethyl benzene	8020	5	2028	GK
Toluene	8020	5	11678	GK
Xylenes	8020	5	17014	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC.

C/GM

0691/91-0636-

QUANT REPORT

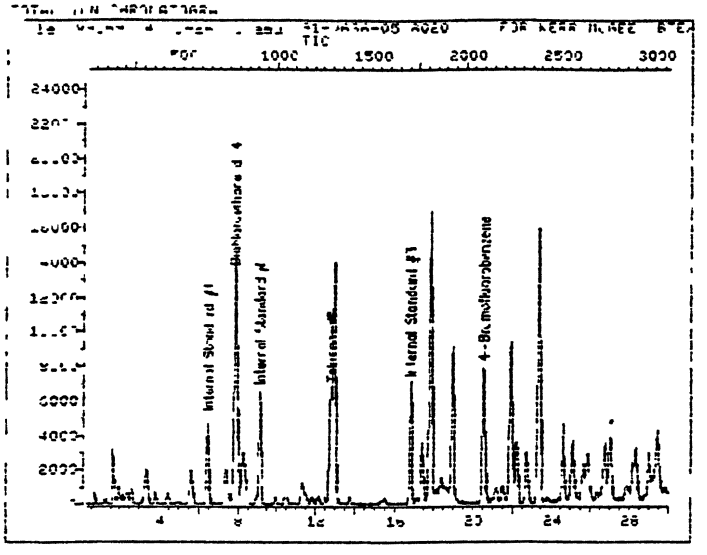
Operator ID SEORGE Quant Rev 6 Quant Time 91Jo1[illegible]
Output File [illegible]80B69 QO Injected at 9[illegible]
Data File [illegible]80B69 QA Dilution Factor 1.00[illegible]
Area [illegible]
Misc [redacted] STE[illegible] DIL 1 100

LO File IDUOA9 QT
Fi[illegible]e Daily Cal via Single Point at 50 ug L 30M LB-62-
Last Calibration 91Jo17 13 26

	Compound	R T	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 42	123 0	5539	50 00	UG L	93
2)	ACROLEIN	4 41	56 0	823	50 10	UG L	100
3)	ACRYLONITRILE	2 32	53 0	291	6 45	UG/L	100
10)	Acetone	3 31	43 0	3056	93 93	UG L	100
10)	1,2-Dichloroethane-d4 *****	7 79	65 0	12312	50 79	UG L	94
4	1,2-Dichloroethane	7 96	62 0	7736	26 73	UG L	44
10)	*1,4-Difluorobenzene	9 07	114 0	21064	50 00	UG L	100
11)	Ethyl acetate	3 71	43 0	3056	111 44	UG L	93
33)	Benzene	7 81	78 0	43760	107 20	UG/L	100
21	trans-1,3-Dichloropropene	12 40	75 1	124	71	UG L	100
24	*Chlorobenzene-d5	10 77	117 0	17988	50 00	UG/L	96
29)	Toluene	12 03	92 0	33147	116 78	UG L	98
30	Toluene-d8 ********	12 77	*98 0	20656	51 48	UG/L	98
34	Ethylbenzene	17 39	106 0	3438	20 49	UG L	94
37)	XYLENE (TOTAL)	17 74	106 0	33719M	170 14	UG L	98
44)	Bromofluorobenzene ********	20 51	95 0	13718M	52 45	UG L	

* Compound is ISTD

(1) 10.20 ug/L.
(22) 11.19 ug/L
(71) 0.28 ug/L
(72) 1.14 ug/L



Data File V8069 04 Quant Output File [illegible]

Area 91-1863A-05 8020

Misc [redacted] BTEX DIL 1 100

Id File IOUDAY QT

Title Daily Cal via Single Point at 50 ug/L 30M DB-624

Last Calibration 910617 13 26

Operator ID GEORGE

Quant Time 910617 23 49

Injected at 910617 23 13

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[redacted]

ATTN TIM BENT

SAMPLE ID: BMW-13

DATE RECEIVED 06/17/91

DATE ANALYZED 06/17/91
DATE REPORTED 06/20/91
REPORT NUMBER 0636-2

BTEX

PARAMETERS	METHOD	DETECTION LIMIT ug/l	RESULTS ug/l	ANALYST
Benzene	8020	5	<5	GK
Ethyl benzere	8020	5	<5	GK
Toluene	8020	5	<5	GK
Xylenes	8020	5	<5	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC.

QUANT REPORT

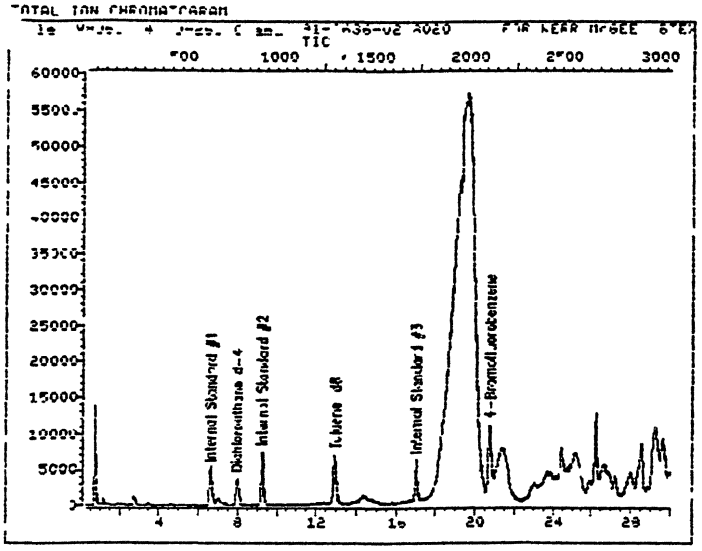
Operator ID SEOWLE Quant Rev: 6 Quant Time 910617 20 28
Output File ^U8U63 QO Injected at 910617 19 57
Data File U8063 U4 Dilution Factor 1 00000
Name 91-063o-02 8020
Misc FOR [redacted] BTEX

ID File IDV0A9 QT
Title Daily Cal v a Single Point at 50 ug/L 30M DB-624
Last Calibration 910617 18 26

	Compound	RT	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 57	128 0	7139	50 00	UG L	96
2)	ACROLEIN	4 55	56 0	182	15 74	UG L	100
9)	Trichlorofluoromethane	2 73	101.0	3536	6 96	UG L	85
10)	Acetone	2 92	43 0	284	5 32	UG L	100
15)	Chloroform	6 95	83 0	2488	4 53	UG L	82
16	1,2-Dichloroethane-d4 *****	7 93	65 0	15673	50 15	UG L	99
18)	*1,4-Difluorobenzene	9 21	114 0	27898	50 00	UG L	100
33)	*Chlorobenzene-d5	16 96	117 0	17465	50 00	UG L	97
49)	Toluene-d8 ********	12 92	98 0	23555	60 47	UG L	90
64)	Bromofluorobenzene ********	20 71	95 0	16425	64 11	UG L	82
67)	1,2 - DICHLOROBENZENE	25 10	146 0	101	25	UG L	97

Compound as ISTD

No RC 20 Compounds to report



Data File >V8063 V4 Quant Output File ^V8063 .QO
Name 91-[redacted]6-02 8020
Misc. [redacted] BTEX

Id File IDV0A9 .QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910617 18 26

Operator ID GEOPGE
Quant Time 910617 20 28
Injected at 910617 19 57

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[redacted]

ATTN: TIM BENT

SAMPLE ID· BMW-15

DATE RECEIVED 06/17/91

DATE ANALYZED· 06/17/91
DATE REPORTED· 06/20/91
REPORT NUMBER 0636-3

BTEX

PARAMETERS	METHOD	DETECTION LIMIT ug/l	RESULTS ug/l	ANALYST
Benzene	8020	5	<5	GK
Ethyl benzene	8020	5	<5	GK
Toluene	8020	5	<5	GK
Xylenes	8020	5	<5	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC

GM

06/21/91 063

QUANT REPORT

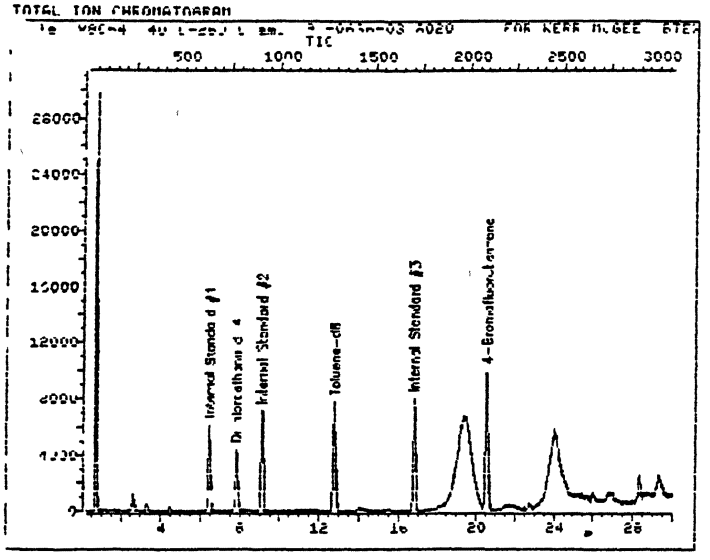
Operator ID GEORGE Quant Rev 6 Quant Time 910617 21 31
Output File >V8064 QD Injected at 910617 20:30
Data File >V8064 V4 Dilution Factor 1 000000
Name 91-0636-03 9020
Misc [redacted] 8TE<.

ID File IDV0A9 .QT
Title Daily Cal via Single Point at 50 ug L 30M JB-624
Last Calibration 910617 18.26

	Compound	R T.	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 42	128 0	6056	50 00	UG L	88
2)	ACROLEIN	4 43	56.0	121	10 17	UG L	109
3)	Methylene Chloride	3 30	84 0	776	3 91	UG L	97
9)	Trichlorofluoromethane	2 59	101 0	3086	7 16	UG/L	79
10)	Acetone	3 30	43 0	169	3 73	UG/L	100
16)	1,2-Dichloroethane-d4 *****	7 78	65 0	13482	50 85	UG/L	98
17)	1,2-Dichloroethane	9 09	62 0	941	2 93	UG L	75
18	*1,4-Difluorobenzene	9 07	114 0	24501	50 00	UG/L	101
30)	Benzene	7 79	78 0	287	63	UG/L	100
33)	*Chlorobenzene-d5	16 77	117 0	21215	50 00	UG/L	97
39)	Toluene-d8 ********	12 77	98 0	23478	49 62	UG/L	87
41)	Bromofluorobenzene ********	20.53	95 0	16799	52.38	UG L	83

* Compound is ISTD

No SC2C Compounds
to Report



Data File \U8U64 U4 Quant Output File \U8U64 QO
Name 91-U636-U3 9U20
Misc [redacted] BTE

Id File ID\U0A9 U1
Title Daily Cal via Single Point at 50 ug L 30M DB-624
Last Calibration 91U617 18 45

Operator ID GEOPGE
Quant Time 91U617 21 01
Injected at 91U617 20 39

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[redacted]
ATTN TIM BENT

SAMPLE ID BMW-16

DATE RECEIVED 06/17/91

DATE ANALYZED 06/17/91
DATE REPORTED 06/20/91
REPORT NUMBER 0636-4

BTEX

PARAMETERS	METHOD	DETECTION LIMIT ug/l	RESULTS ug/l	ANAL'ST
Benzene	8020	5	1675	GK
Ethyl benzene	8020	5	<5	GK
Toluene	8020	5	27	GK
Xylenes	8020	5	817	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC

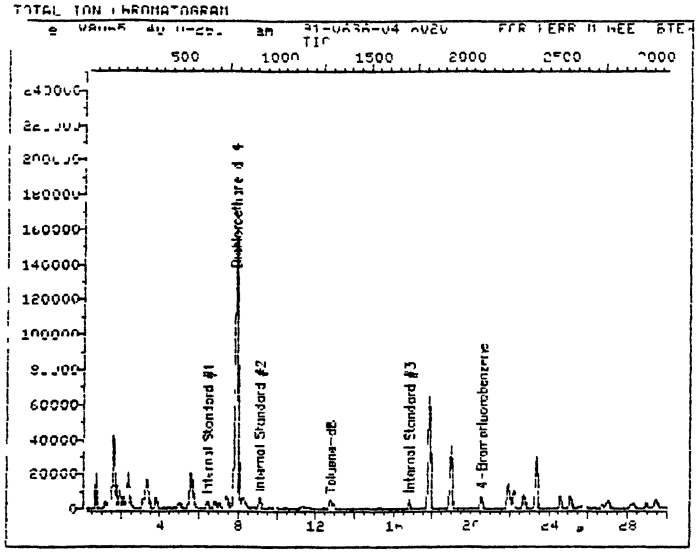
QUANT REPORT

Operator ID SEUPOE Quant Method Quant Time 910617 21 36
Output File V8065 QD Injected at 910617 21 04
Data File V8065 04 Dilution Factor 1.0000
Name 91-06-16-14 2H 0
Misc [redacted] BTE

ID File IDV0A9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910617 16 26

	Compound	RT	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6.40	128	4916	50.00	UG/L	91
2)	ACROLEIN	4.21	56	1611	149.59	UG/L	100
3)	ACRYLONITRILE	3.13	53	3819	96.42	UG/L	100
4)	Chloromethane	1.62	50	[illegible]	64.62	UG/L	9
5)	Trichlorofluoromethane	2.58	101	2232	6.38	UG/L	96
10)	Acetone	3.30	43	23926	651.30	UG/L	100
16)	1,2-Dichloroethane-d4 *****	7.80	65	10817	50.27	UG/L	94
17)	1,2-Dichloroethane	7.83	62	8360	32.12	UG/L	5
18)	*1,4-Difluorobenzene	9.07	114	19649	50.00	UG/L	100
22)	Vinyl Acetate	3.77	43	2499	110.48	UG/L	90
40)	Benzene	7.85	78	0 * 61463	1675.21	UG/L	100
44)	*Chlorobenzene-d5	16.79	117	15223	50.00	UG/L	96
45)	Toluene	12.92	92	6389	26.69	UG/L	99
46)	Toluene-d8 ********	12.75	98	17322	52.49	UG/L	99
47)	~~Ethylbenzene~~	~~13.70~~	~~106~~	~~8442~~	~~622.49~~	UG/L	94
48)	XYLENE (TOTAL)	17.30	106	13711	817.52	UG/L	91
49)	Bromofluorobenzene ********	20.53	95	12427	56.18	UG/L	97

* Compound is ISTD



Data File V8U65 U4 Quant Output File U8U6[illegible] U
Name [illegible] 20_0
Misc [redacted] STE[illegible]

Id File IDUUA[illegible] QT
Title Daily Cal via Single Point at 50 ug L 30M DB-624
Last Calibration [illegible]

Operator ID GEORGE
Quant Time [illegible]
Injected at [illegible]

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[redacted]
ATTN TIM BENT

SAMPLE ID BMW-17

DATE RECEIVED 06/17/91

DATE ANALYZED 06/17/91
DATE REPORTED 06/20/91
REPORT NUMBER 0636-7

BTEX

PARAMETERS	METHOD	DETECTION LIMIT ug/l	RESULTS ug/l	ANALYST
Benzene	8020	5	4934	GK
Ethyl benzene	8020	5	<5	GK
Toluene	8020	5	296	GK
Xylenes	8020	5	630	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC

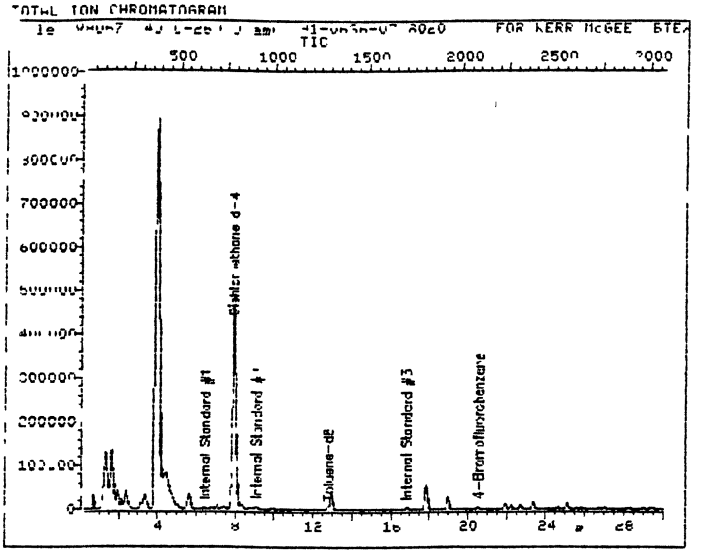
QUANT REPORT

Operator ID GEUMGE Quant Rev 6 Quant Time 910617 22 44
Output File V8U617 QD Injected at 910617 22 11
Data File >V8U617 QD Dilution Factor 1.00000
Name 91-063m-07 400 U
Misc [redacted] BTEX

ID File IDVOAY QT
Title Daily Cal via Single Point at 50 ug L 30M DB-624
Last Calibration 910617 Id 26

	Compound	R T	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 42	128 0	5418	50 00	UG L	92
2)	ACROLEIN	3 96	56 0	265493	264.99	UG L	103
3)	ACRYLONITRILE	3 95	53 0	79492	1813 19	UG L	1 00
4	Chloromethane	2 11	50 0	1406	32 03	UG L	46
5)	Trichlorofluoromethane	2 57	101 0	2057	5 34	UG L	60
10)	Acetone	3 34	43 0	76597	1940 39	UG L	101
11)	Carbon Disulfide	3 90	76 0	181	53	UG L	100
12)	1,1-Dichloroethane	5 01	63 0	124	40	UG L	75
16)	1,2-Dichloroethane-d4 *****	7 85	65 0	11356	47 87	UG L	96
17)	1,2-Dichloroethane	8 00	62 0	230123	902 19	UG L	96
18)	*1,4-Difluorobenzene	9 07	114 0	21995	50 00	UG L	100
1	Vinyl Acetate	3 34	43 0	78597	2824 53	UG L	70
	Benzene	7 88	78 0	202191	4934 02	UG L	100
31)	trans-1,3-Dichloropropene	12 94	75 0	234	1 24	UG L	100
34)	*Chlorobenzene-d5	16 78	117 0	17609	50 00	UG L	9
35)	4-Methyl-2-Pentanone (MIBK)	12 89	43 0	3177	22 04	UG L	91
38)	Toluene	12 93	92 0	82298	296 19	UG L	94
39	Toluene-d8 ********	12 76	98 0	20813	52 23	UG L	86
41)	~~Ethylbenzene~~	~~17 80~~	~~106~~ 0	~~92146~~	~~444 91~~	UG L	77
42)	XYLENE (TOTAL	17 78	106 0	122115M	629 53	UG L	97
43)	Bromofluorobenzene ********	20 63	95 0	14760	56 45	UG L	87

* Compound to be



Data File V9067[illegible]04 Quant Output File V9067 QO
Name 91-0[illegible]3020
Misc [redacted] BTEX

Id File IDV0A? QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910617 18 26

Operator ID GEORGE
Quant Time 910617 22 42
Injected at 910617 22 11

Thurs June 13, 1991

On-site at [redacted] to do Tim Bent's samples

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE
194	15	BTEX Std	B	27	10.81 ppm	100 ul
			T	39	10 89	
			E	56	11 24	
			o X	74	11 44	
195	15	BTEX Std	B	27	10.81	100 ul
			T	38	10 89	
			E	55	11.24	
			O-X	72	11 44	
196	15	BLANK (zero air)		No Peaks		100 ul
197	15	PUMP AIR (BLANK)	B	27	4.12 ppm	100 ul
198	15	PUMP AIR (BLANK)	B	27	4.64 ppm	100 ul
		Tim had made repairs (using glue) to the small aquarium air pump used to fill gas bags				
199	15	BLANK (zero air)		No peaks		100 ul
200	15	BTEX Std	B	26	10.81 ppm	100 ul
			T	36	10 89	
			E	51	11 24	
			O-X	67	11 44	

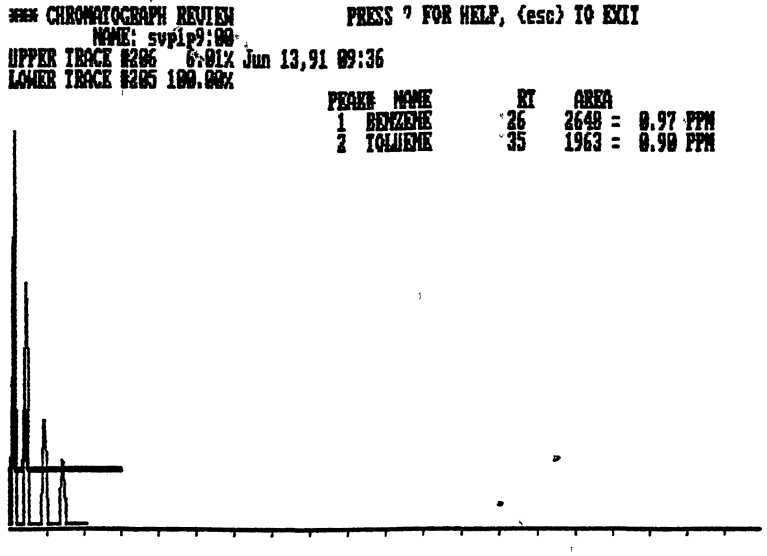
Roy K Adamson 6/13/91

[redacted]

23

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE
201	15	PUMP AIR	B	26	1.15 ppm	100 ml
			T	36	19.07	
			E	53	9.50	
		Sample 201 was from pump Air after just having filled up some air bags				
202	15	Pump Air	T	36	6.02 ppm	100 ml
203	15	Pump Air	T	35	2.15 ppm	100 ml
204	15	SVP1P 9:00 (SVP1 PORT)	No Peaks			100 ml
205	15	BTEX Std	B	26	10.81 ppm	100 ml
			T	35	10.89	
			E	50	11.24	
			o-X	65	11.44	
good → 206	15	SVP1P 9:00 (SVP1 PORT)	B	26	0.97 ppm B	100 ml
			T	35	0.90 T	
Good data		PID reading ~ 18ppm				
207	15	SVP2P 9:00 (SVP2 PORT)	~~When~~ Went off scale (top of screen)			100 ml 50% zero air 50% sample
208	15	SVP2P 9:00 (SVP2 PORT)	Went off scale (top of screen)			100 ml 75% zero air 25% sample
209	15	Blank	B	26	2.70	100 ml
			T	35	59.50	
			E	52	19.81	

Signature: Roy K Widmann Date: 6/13/91

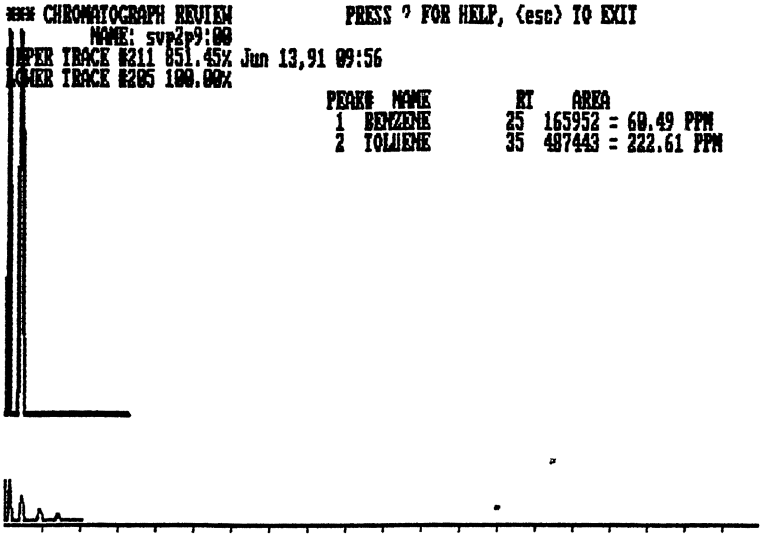

**** CHROMATOGRAPH REVIEW
PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp1p9:00
UPPER TRACE #206 6.01X Jun 13,91 09:36
LOWER TRACE #205 100.00X
PEAK# NAME RT AREA
1 BENZENE 26 2648 = 0.97 PPM
2 TOLUENE 35 1963 = 0.90 PPM

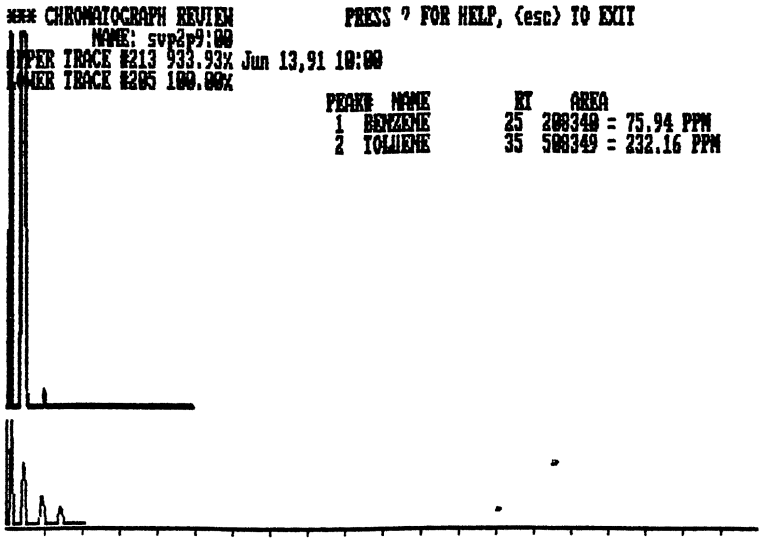
[redacted]

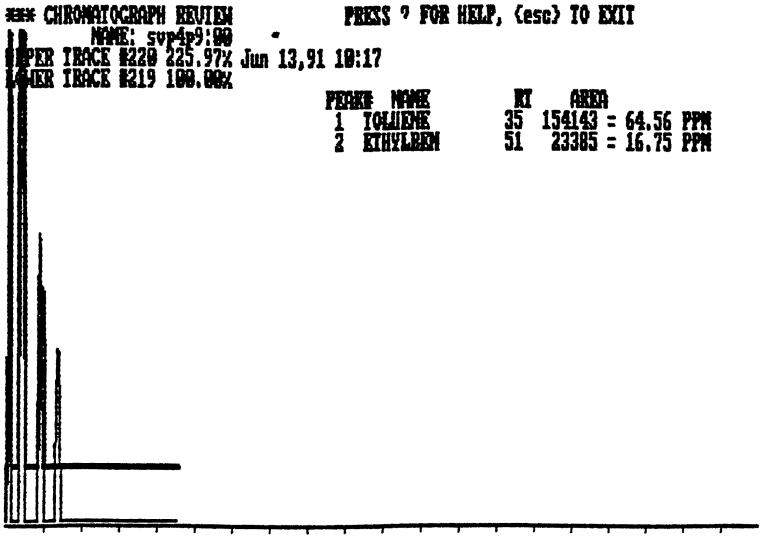
24

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
210	15	SVP2P9'00	B	26	23.24 ppm	100ml	90% air
–		(SVP2 PORT)	T	35	180.59		10% sam
good → 211	15	SVP2P9.00	B	25	60.49 ppm	100ml	90% air
		(SVP2PORT)	T	35	222.61	5415 ppm B	10% sam
					÷ 0.111	2,005 ppm T	
212	15	Bad injection					
good → 213	15	SVP2P9 00	B	25	75.94 ppm	100ml	80% air
		(SVP2 PORT)	T	35	232.16	684 ppm	10% samp
						2,092 ppm	
		PID reading: 22 (constant)					
		106 (diluted)			avg B = 615 ppm		
					avg T = 2,049 ppm		
214	15	BLANK	T	35	29.97	100ml	
			E	52	11.65		
215	15	BLANK	T	35	3.31	100ml	
216	15	BLANK	T	35	1.97	100ml	
217	15	BLANK	T	35	1.21	100ml	
218	15	BLANK	No Peaks				
219	15	BTEX Std	B	25	10.81 ppm	100ml	
			T	35	10.89		
			E	49	11.24		
			X	63	11.44		
220	15	SVP4P9 00	B	did not call		100ml	90% air
		(SVP4 PORT)	T	35	64.56 = 582	T	10% samp
			E	51	16.75 = 151	E	
					111		

[redacted] Roy K Widmann Date: 6/13/91


*** CHROMATOGRAPH REVIEW
PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp2p9:00
UPPER TRACE #211 851.45% Jun 13,91 09:56
LOWER TRACE #205 100.00%
PEAK# NAME RT AREA
1 BENZENE 25 165952 = 60.49 PPM
2 TOLUENE 35 487443 = 222.61 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp2p9:00
UPPER TRACE #213 933.93% Jun 13,91 10:00
LOWER TRACE #205 100.00%
PEAK# NAME RT AREA
1 BENZENE 25 208340 = 75.94 PPM
2 TOLUENE 35 580349 = 232.16 PPM

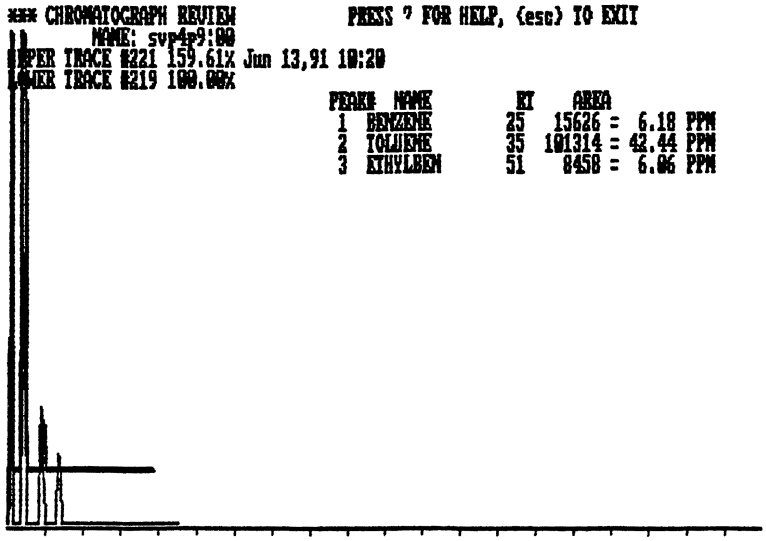

*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp4p9:00
UPPER TRACE #220 225.97% Jun 13,91 10:17
LOWER TRACE #219 100.00%
PEAK# NAME RT AREA
1 TOLUENE 35 154143 = 64.56 PPM
2 ETHYLBEN 51 23385 = 16.75 PPM

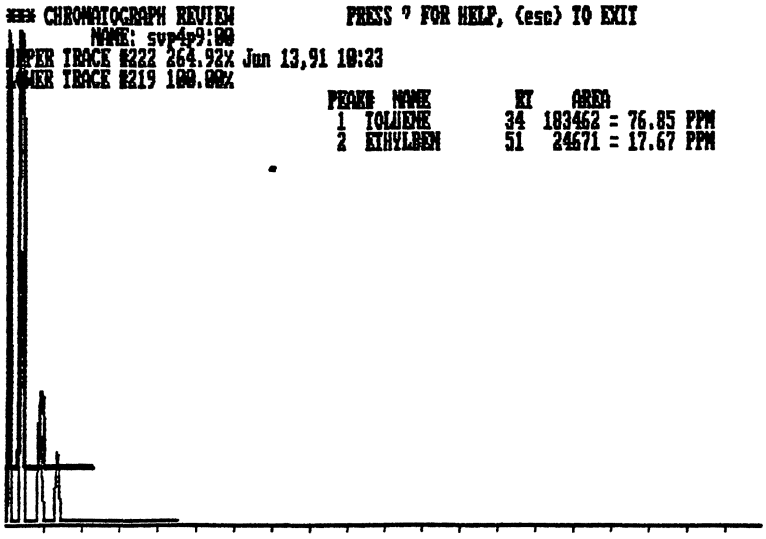
[redacted]

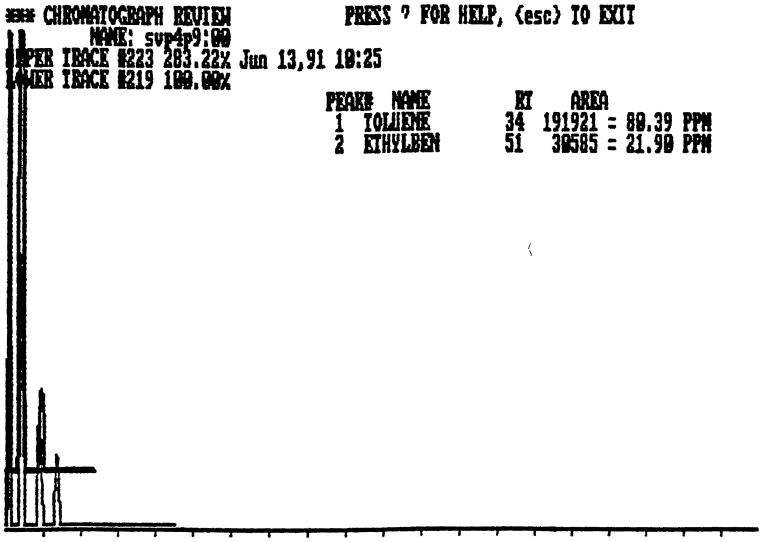
25

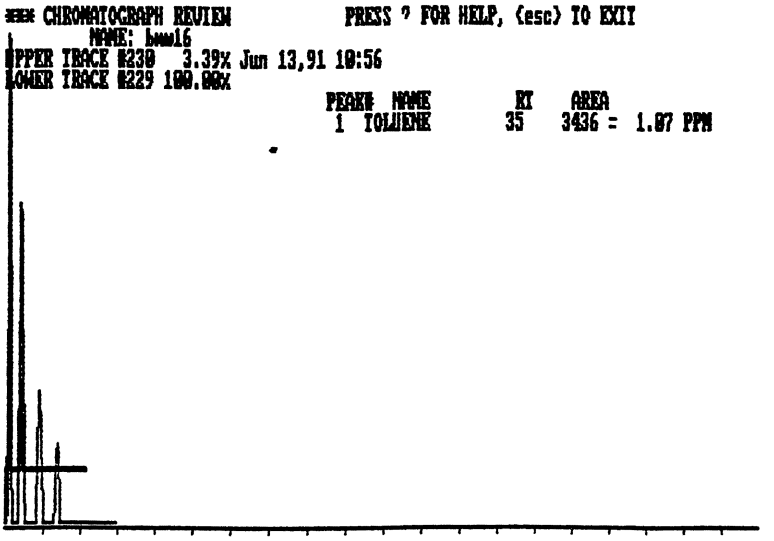
	RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
	221	15	SVP4P9.00 (SVP4PORT)	B	35	6.18 = 56	100 ul	90% air 10% Sam
				T	35	42.44 = 382		
				E	51	6.06 = 55		
	222	15	SVP4P9.00 (SVP4PORT)	B	Did not call		100 ul	90% air 10% Sam
				T	34	76.85 = 692		
				E	51	17.62 = 159		
	223	15	SVP4P9.00 (SVP4PORT)	B	Did not call (<1 ppm)		100 ul	90% air 10% Sam
	avg. B = 56			T	34	80.39 = 724		
	T = 595			E	51	21.90 = 197		
	E = 141							
	224	15	BLANK	T	35	9.82	100 ul	
	225	15	BLANK	T	35	3.65	100 ul	
	226	15	BLANK	T	35	1.07	100 ul	
	227	15	BLANK	No Peaks			100 ul	
	228	15	BLANK	No Peaks			100 ul	
	229	15	BTEX Std	B	35	1.81	100 ul	
				T	35	10.89		
				E	49	11.24		
				X	63	11.44		
	230	15	BMW 16	B	Did not call (<<1 ppm)		100 ul	trc B
				T	35	1.07		
	231	15	BMW 16	B	Did not call (<<1 ppm)		100 ul	
				T	Did not call (<<1 ppm)			

Roy K Widmann 6/13/91


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp4p9:00
UPPER TRACE #221 159.61% Jun 13,91 10:20
LOWER TRACE #219 100.00%
PEAK# NAME RT AREA
1 BENZENE 25 15626 = 6.18 PPM
2 TOLUENE 35 101314 = 42.44 PPM
3 ETHYLBEN 51 8458 = 6.06 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp4p9:00
UPPER TRACE #222 264.92% Jun 13,91 10:23
LOWER TRACE #219 100.00%
PEAK# NAME RT AREA
1 TOLUENE 34 183462 = 76.85 PPM
2 ETHYLBEN 51 24671 = 17.67 PPM


**** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp4p9:00
UPPER TRACE #223 203.22% Jun 13,91 10:25
LOWER TRACE #219 100.00%
PEAK# NAME RT AREA
1 TOLUENE 34 191921 = 80.39 PPM
2 ETHYLBEN 51 30585 = 21.90 PPM


**** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bww16
UPPER TRACE #230 3.39% Jun 13,91 10:56
LOWER TRACE #229 100.00%
PEAK# NAME RT AREA
1 TOLUENE 35 3436 = 1.07 PPM

[redacted]

26

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE
232	15	BMW 16	B	Did not call (<< 1 ppm)		100 ml
			T	Did not call (<< 1 ppm)		
233	15	BLANK				100 ml
234	15	BTEX std	B	26	10.81	100 ml
			T	35	10.89	
			E	49	11.24	
			X	63	11.44	
235	15	BMW 14	B	Did not call (<< 1 ppm)		100 ml
			T	35	3.84	
236	15	BMW 14	B	Did not call << 1 ppm		100 ml
			T	Did not call << 1 ppm		
237	15	BMW 14	T	Did not call << 1 ppm		100 ml
238	15	BMW 15	No Peaks			100 ml
239	15	BMW 15	No Peaks			100 ml
240	15	BTEX std	B	25	10.81	100 ml
			T	34	10.89	
			E	49	11.24	
			X	63	11.44	
241	15	Pump Air	B	Did not call	<< 1 ppm	100 ml
			T	34	2.02	

trc B, trc T

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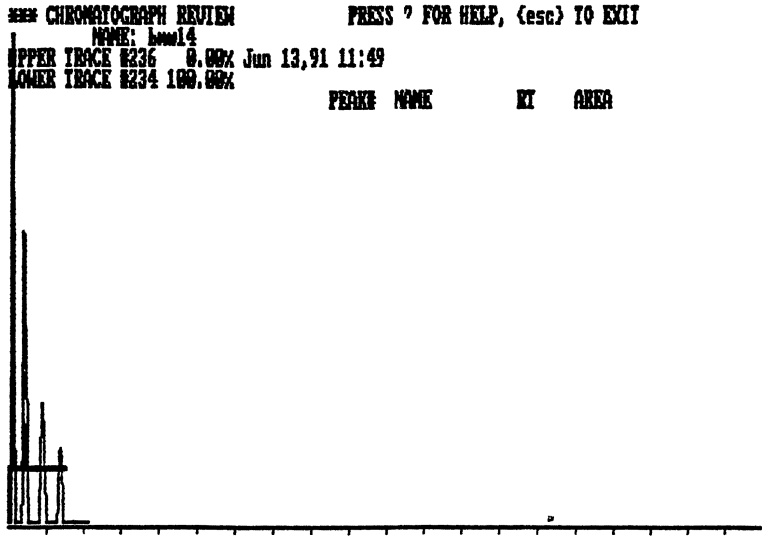
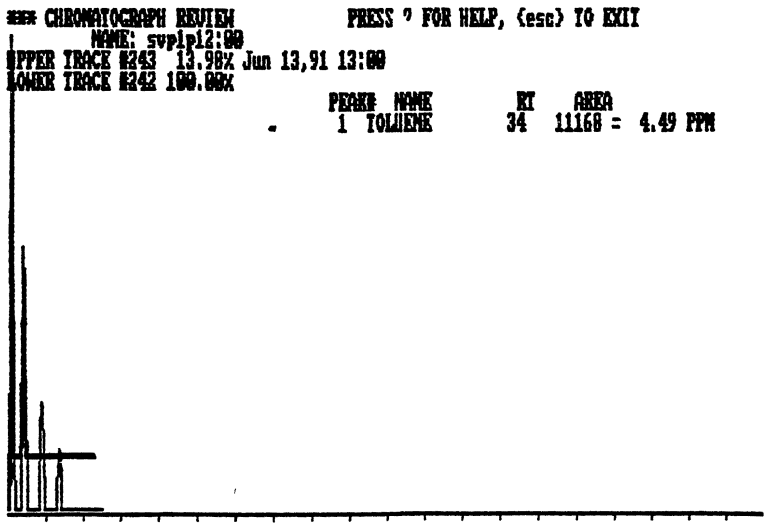

*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: hmw14
UPPER TRACE #236 0.00% Jun 13,91 11:49
LOWER TRACE #234 100.00%
PEAK# NAME RT AREA


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svpip12:00
UPPER TRACE #243 13.98% Jun 13,91 13:00
LOWER TRACE #242 100.00%
PEAK# NAME RT AREA
1 TOLUENE 34 11168 = 4.49 PPM

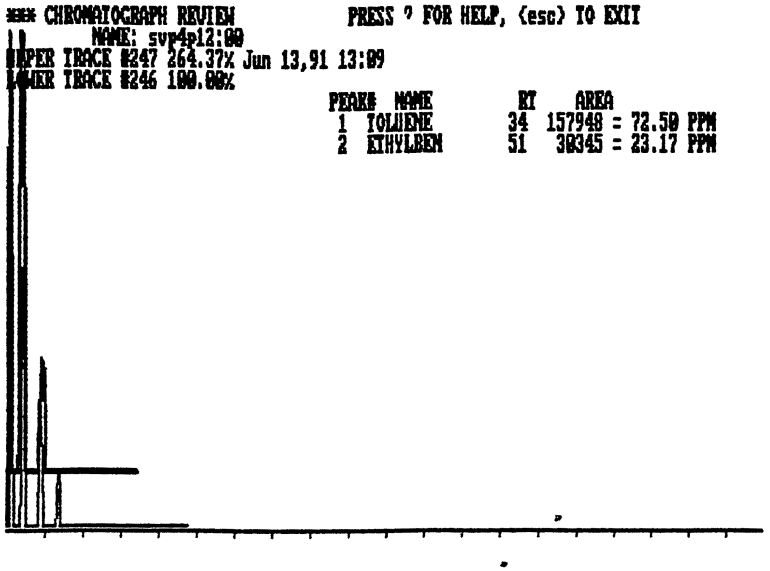
[redacted]

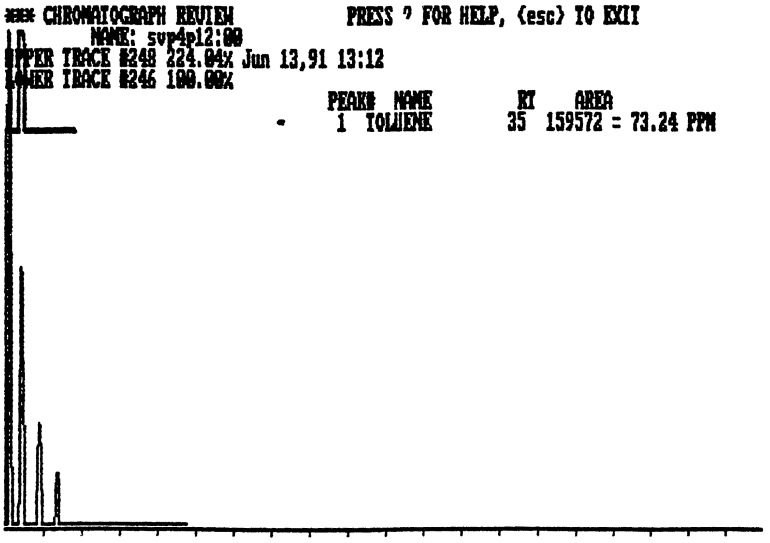
27

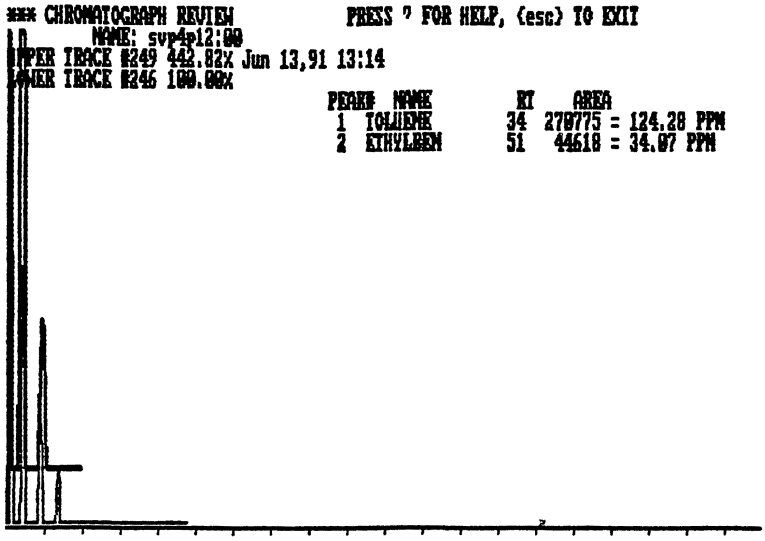
RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE
242	15	BTEX Std	B	25	10.81	100 ml
			T	34	10.89	
			E	49	11.24	
			X	63	11.44	
243	15	SVP1P12.00 (SVP1 PORT)	B	Did not call	<1 ppm	100 ml
			T	34	4.49	
Good → 244	15	SVP1P12 00 (SVP1 PORT)	B	Did not call	<1 ppm	100 ml
			T	Did not call	<1 ppm	
Good → 245	15	SVP1P12 00 (SVP1 PORT)	B	Did not call	<1 ppm	100 ml
			T	Did not call	<1 ppm	
246	15	BTEX Std	B	25	10.81	100 ml
			T	35	10.89	
			E	49	11.24	
			X	63	11.44	
					.5/.111 = 4.5	
247	15	SVP4P 12:00 (SVP4 PORT)	B	Did not call	<1 ppm	100 ml
Good →			T	34	72.50	653
			E	51	23.17	209
					.111	
248	15	SVP4P 12:00 (SVP4 PORT)	B	Did not call	<1 ppm	100 ml
			T	35	73.24 = 660	
					.11	
249	15	SVP4P.12 00 (SVP4 PORT)	B	Did not call		100 ml
Probably bad septum →			T	34	124.28 = 1120	
			E	51	34.07 = 307	
					11	
250	15	SVP4P 12:00 (SVP4 PORT)	Bad injection			

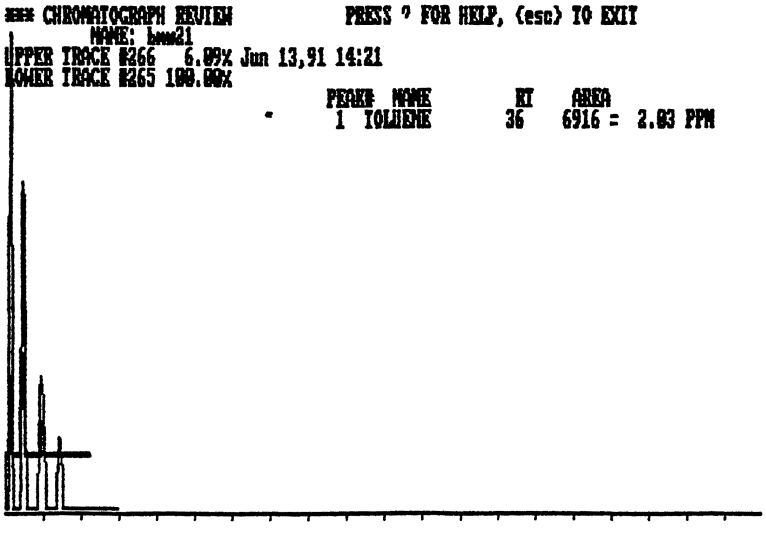
avg ~~TCE B~~ 4.5 B
811 T
258 E

Roy K Widmann
6/13/91


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp4p12:00
UPPER TRACE #247 264.37% Jun 13,91 13:09
LOWER TRACE #246 100.00%
PEAK# NAME RT AREA
1 TOLUENE 34 157948 = 72.50 PPM
2 ETHYLBEN 51 30345 = 23.17 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp4p12:00
UPPER TRACE #248 224.04% Jun 13,91 13:12
LOWER TRACE #246 100.00%
PEAK# NAME RT AREA
1 TOLUENE 35 159572 = 73.24 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: svp4p12:00
UPPER TRACE #249 442.82% Jun 13,91 13:14
LOWER TRACE #246 100.00%
PEAK# NAME RT AREA
1 TOLUENE 34 2797775 = 124.28 PPM
2 ETHYLBENZ 51 44618 = 34.07 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw21
UPPER TRACE #266 6.09% Jun 13,91 14:21
LOWER TRACE #265 100.00%
PEAK# NAME RT AREA
1 TOLUENE 36 6916 = 2.03 PPM

[redacted]

28

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
251	15	BTEX std	B	25	10.81 ppm	100 ul	
			T	35	10.89		
			E	49	11.24		
			o-X	63	11.44		
252	15	SVP2P12:00 (SVP2 PORT)	went off scale (top of screen)			100 ul	90% air 10% sample
253	15	SVP2P12:00 (SVP2 PORT)	went off scale (top of screen)			100 ul	90% air 10% sample
254	15	SVP2P12 00 (SVP2PORT)	went off scale (top of screen)			100 ul	~~90% air 10% sample~~ 95% air 5% sample
255	15	BTEX Std					
CHANGE SEPTUM — First one lasted for 60 injections							
255	15	BTEX Std	B	26	10.81	100 ul	~~90% air 10% sample~~
			T	36	10.89		
			E	50	11.24		
			X	63	11.44		
256	15	SVP2P12:00 (SVP2PORT)	went off scale (top of screen)			100 ul	90% air 10% sample
257	15	BTEX Std	B	27	10.81	25 ul	
			T	36	10.89		
			E	Did not call			

Roy K Wehmann 6/13/91

[redacted]

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
258	15	SVP2P12 00 (SVP2PORT)	went off scale (top of screen)			25 ul	50% 50%
259	15	SVP2P12 00 (SVP2PORT)	went off scale (top of screen)			25 ul	80% 20%
260	15	Blank	several peaks			100 ul	
261	15	Blank	T	36	20.50	100 ul	
			Unk	53	22.93		
262	15	Blank	T	36	9.33	100 ul	
			Unk	53	6.40		
263	15	Blank	No peaks			100 ul	
264	15	Blank	No peaks			100 ul	
265	15	BTEX Std	B	26	10.81 ppm	100 ul	
			T	36	10.89		
			E	50	11.24		
			X	65	11.44		
266	15	BMW 21	B	Did not call	<1 ppm	100 ul	
			T	36	2.03 ppm		
			E	Did not call	<1 ppm		
267	15	BMW 21	B	Did not call	<1 ppm	100 ul	
			T	Did not call	<1		
268	15	BMW 21	T	Did not call	<1 ppm	100 ul	

Signature Roy K Widmann Date 6/13/91

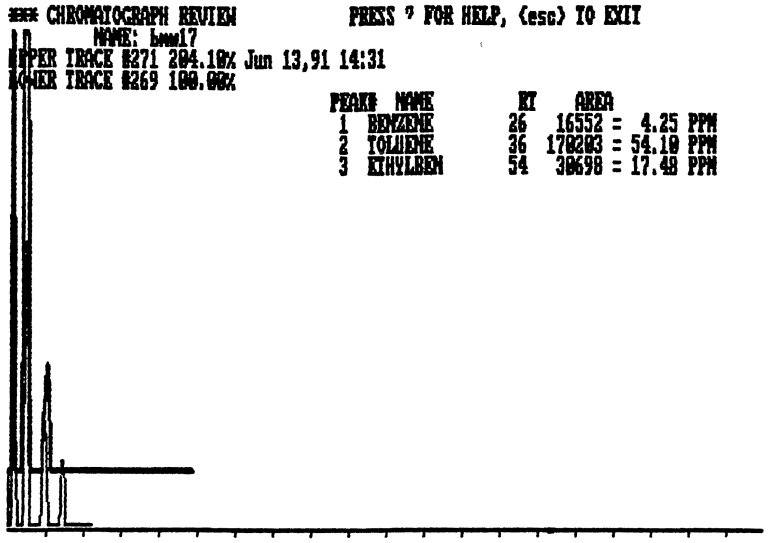
Witness

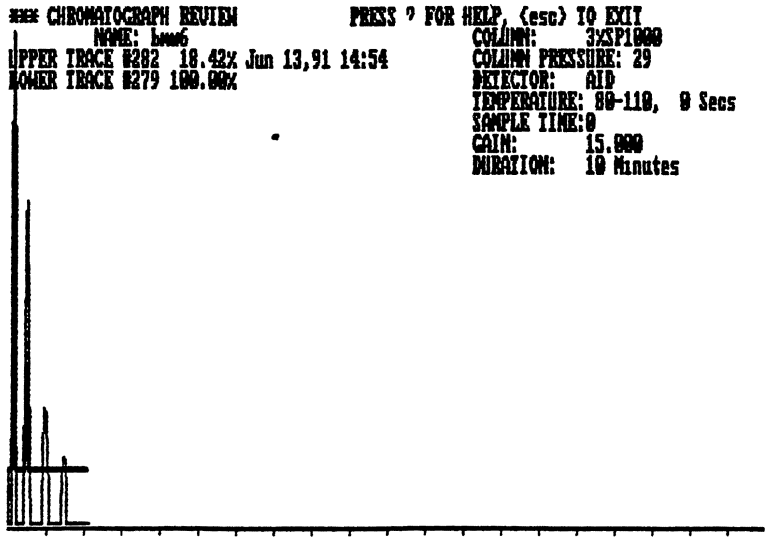
[redacted]

30

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE
269	15	BTEX Std	B	26	10.81 ppm	100 ml
			T	36	10.89	
			E	50	11.24	
			X	65	11.44	
270	15	BMW 17	B	Did not call		100 ml
			T	35	57.87 ppm	
			E	52	17.62	
271	15	BMW 17	B	26	4.25	100 ml
			T	36	54.10	avg = 56
			E	54	17.48	avg = 17.6
272	15	BMW 8 / bad injec	B	Did not call	< 1 ppm	100 ml
273	15	BTEX Std	B	26	10.81	100 ml
			T	36	10.89	
			E	51	11.24	
			X	65	11.44	
274	15	BMW 8	went off scale (top of screen)			100 ml
275	15	Blank	B	Did not call		100 ml
			T	37	7.98	
			E	53	2.98	
276	15	Blank	T	37	4.49	100 ml
277	15	Blank	T	37	0.68	100 ml
278	15	Blank	T	37	0.48	100 ml

Roy K Widmann 6/13/91

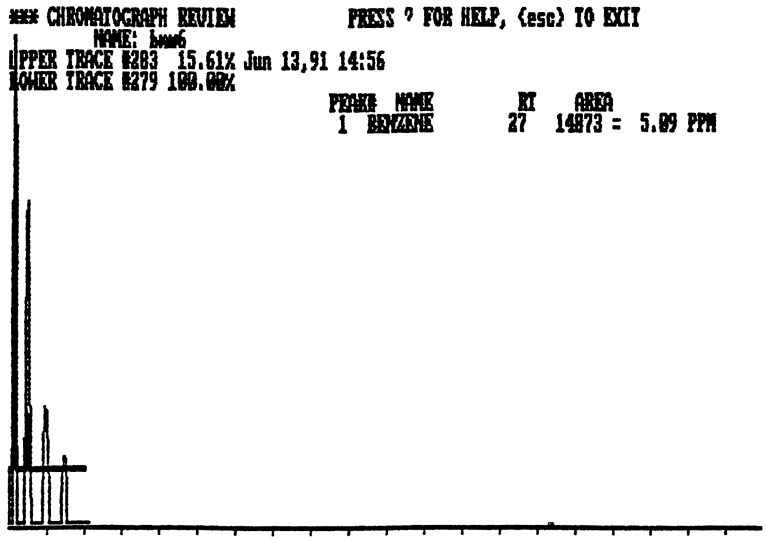

*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw17
UPPER TRACE #271 204.18% Jun 13,91 14:31
LOWER TRACE #269 100.00%
PEAK# NAME RT AREA
1 BENZENE 26 16552 = 4.25 PPM
2 TOLUENE 36 178203 = 54.10 PPM
3 ETHYLBEN 54 30698 = 17.48 PPM

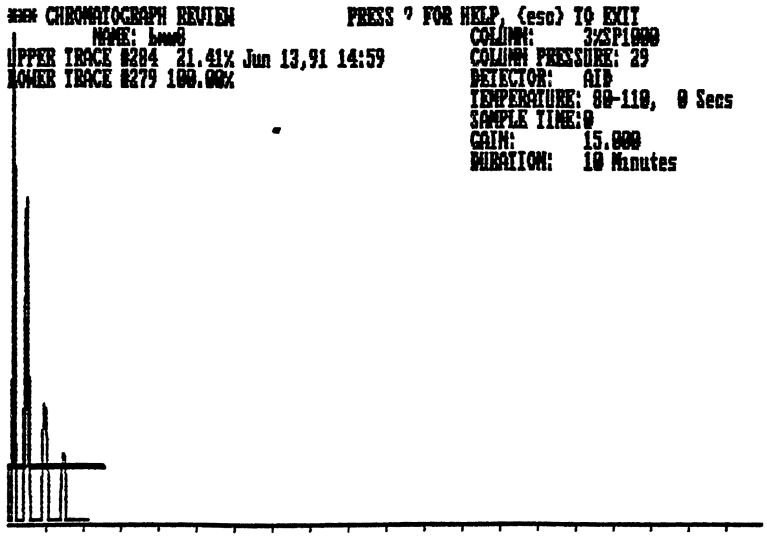

*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw6
UPPER TRACE #282 18.42% Jun 13,91 14:54
LOWER TRACE #279 100.00%
COLUMN: 3%SP1000
COLUMN PRESSURE: 29
DETECTOR: AID
TEMPERATURE: 80-110, 8 Secs
SAMPLE TIME:0
GAIN: 15.000
DURATION: 10 Minutes

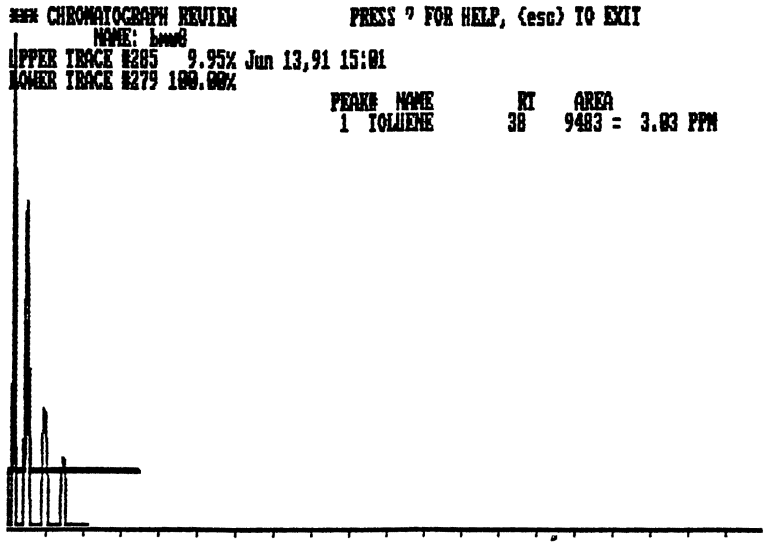
	RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
	279	15	BTEX Std	B	27	10.81 ppm	100 ml	
				T	37	10.89		
				E	51	11.24		
				X	66	11.44		
	280	15	BMW 6	went off scale (top of screen)			100 ml	
	281	15	BMW 6	went off scale (top of screen)			100 ml	90% air 10% sample
good →	282	15	BMW 6	B	27	4.96 = 94	100 ml	95% air
				T	37	0.98 = 19 / .053		5% sample
good →	283	15	BMW 6	B	27	5.09 = 97	100 ml	95% air
				T	37	~~5.10~~ 4.30 ↑ did not call		5% sample
						.053 avg = 96 B		
						x 15 T		
good →	284	15	BMW 8	B	Did not call	<1 ppm	100 ml	95% air
				T	37	6.52 ppm = 124 / .053		5% sample
	285	15	BMW 8	B	Did not call		100 ml	95% air
				T	38	3.03 ppm = 58 / .053		5% sample
good →	286	15	BMW 8	B	Did not call		100 ml	95% air
				T	38	5.13 ppm = 97 / .053 avg = 93 ppm T		5% sample
	287	15	Blank	No peaks			trc. B	
	288	15	Blank	No peaks				

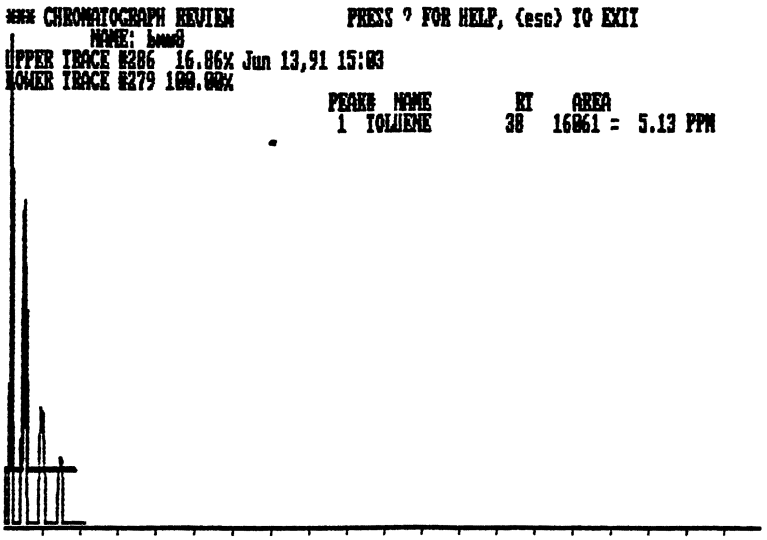
Sign: Roy K Widmann 6/13/91

W -


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmm6
UPPER TRACE #283 15.61% Jun 13,91 14:56
LOWER TRACE #279 100.00%
PEAK# NAME RT AREA
1 BENZENE 27 14873 = 5.09 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmm8
UPPER TRACE #284 21.41% Jun 13,91 14:59
LOWER TRACE #279 100.00%
COLUMN: 3%SP1000
COLUMN PRESSURE: 29
DETECTOR: AIB
TEMPERATURE: 80-110, 0 Secs
SAMPLE TIME:0
GAIN: 15.000
DURATION: 10 Minutes


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw8
UPPER TRACE #285 9.95% Jun 13,91 15:01
LOWER TRACE #279 100.00%
PEAK# NAME RT AREA
1 TOLUENE 38 9493 = 3.03 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw8
UPPER TRACE #286 16.86% Jun 13,91 15:03
LOWER TRACE #279 100.00%
PEAK# NAME RT AREA
1 TOLUENE 38 16061 = 5.13 PPM

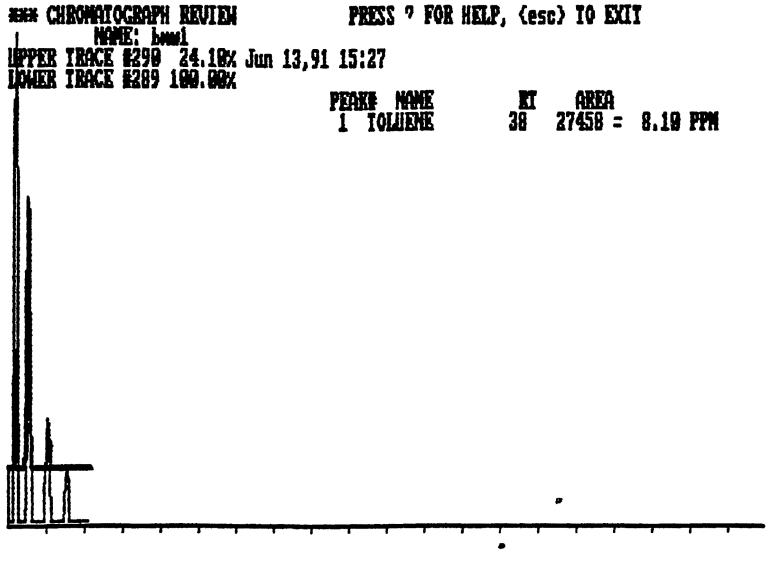
32

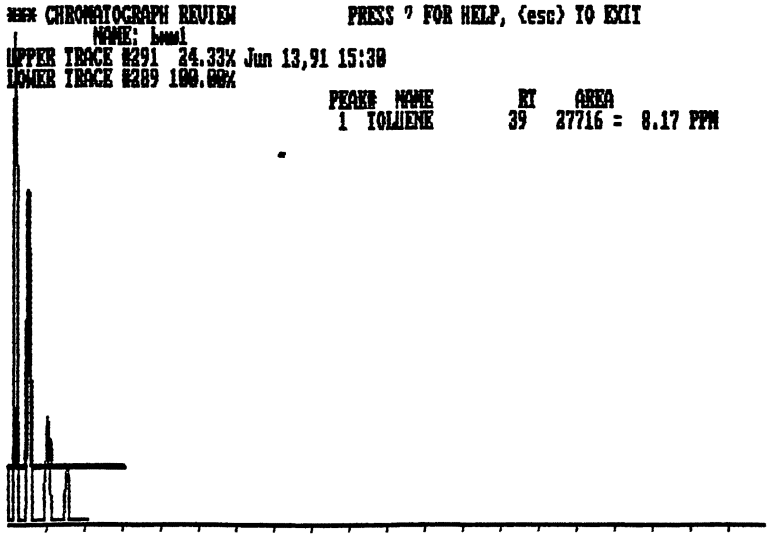
[redacted]

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
289	15	BTEX Std	B	38	10.81	100 ml	
			T	38	10.89		
			E	53	11.24		
			X	68	11.44		
290	15	BMW 1	B	Did not call	< 1 ppm	100 ml	good →
			T	38	8.10		
			E	Did not call	< 1 ppm		
291	15	BMW 1	B	Did not call	< 1	100 ml	good →
			T	39	8.17 ppm	avg - 8.1 I	
			E	Did not call	< 1	trc B	
						trc E	
292	15	BMW 11	T	38	2.75 ppm	100 ml	90% air 10% sample
293	15	BMW 11		went off scale		100 ml	
294	15	BMW 11		went off scale		100 ml	50% air 50% sample
295	15	BMW 11		No peaks		100 ml	90% air 10% sample
296	15	BTEX Std	B	38	10.81	100 ml	
			T	39	10.89		
			E	54	11.24		
			X	69	11.44		
297	15	BMW 11		No peaks		100 ml	90% air 10% sample
298	15	BMW 12		No peaks			

Signature Roy K Wolmann Date 6/13/91

Witness Please sign and date Date


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw1
UPPER TRACE #290 24.18% Jun 13,91 15:27
LOWER TRACE #289 100.00%
PEAK# NAME RT AREA
1 TOLUENE 38 27458 = 8.19 PPM

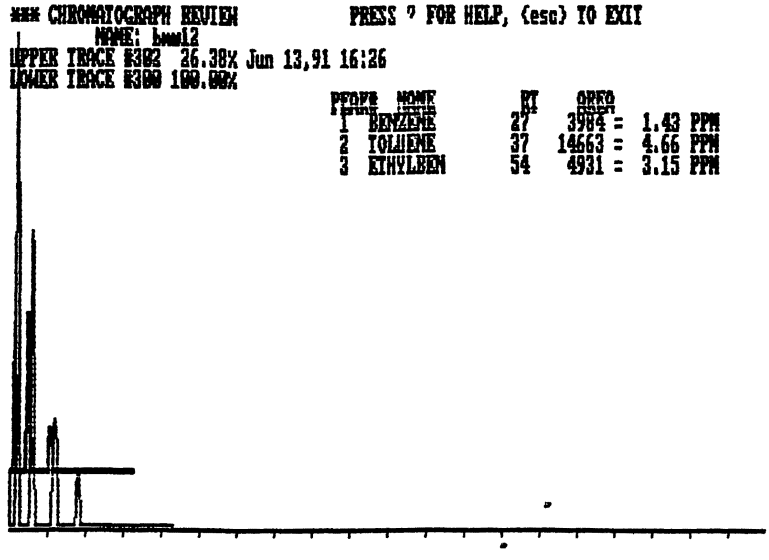

*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw1
UPPER TRACE #291 24.33% Jun 13,91 15:39
LOWER TRACE #289 100.00%
PEAK# NAME RT AREA
1 TOLUENE 39 27716 = 8.17 PPM

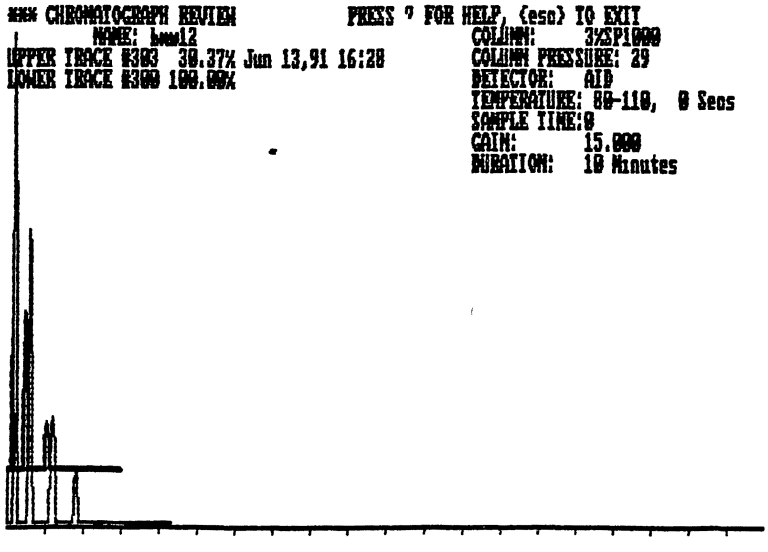
[redacted]

RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
299	15	BTEX Std	B	29	10.81	100 ul	
			T	40	10.89		
			E	55	11.24		
			X	72	11.44		
300	15	BMW 12	No peaks			100 ml	50% air 50% sample
		Change Data Disk					
301	15	BTEX Std	B	30		100 ml	
			T	40			
		Note shift in retention time - clog?	E	56			
			X	72			
302	15	BMW 12	OFF Scale			100 ml	
303	15	BTEX Std	B	30			
			T	41			
			No other peaks				
		Clogged injection port !!! Unclogged it and resumed.					
300	15	BTEX Std	B	28	10.81	100 ml	
			T	40	10.89		
			E	58	11.24		
			X	76	11.44		
301	15	BMW 12	B	Did not call		100 ml	80% air
			T	39	4.30		20% sample
302	15	BMW 12	B	27	1.43	100 ml	
			T	37	4.66		
			E	54	3.15		

Signature Roy K Widmann Date 6/13/91

Witness _____ Date _____


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw12
UPPER TRACE #302 26.38% Jun 13,91 16:26
LOWER TRACE #300 100.00%
PEAK# NAME RT AREA
1 BENZENE 27 3984 = 1.43 PPM
2 TOLUENE 37 14663 = 4.66 PPM
3 ETHYLBEN 54 4931 = 3.15 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw12
UPPER TRACE #303 30.37% Jun 13,91 16:28
LOWER TRACE #300 100.00%
COLUMN: 3%SP1000
COLUMN PRESSURE: 29
DETECTOR: AID
TEMPERATURE: 80-110, 0 Secs
SAMPLE TIME:0
GAIN: 15.000
DURATION: 10 Minutes

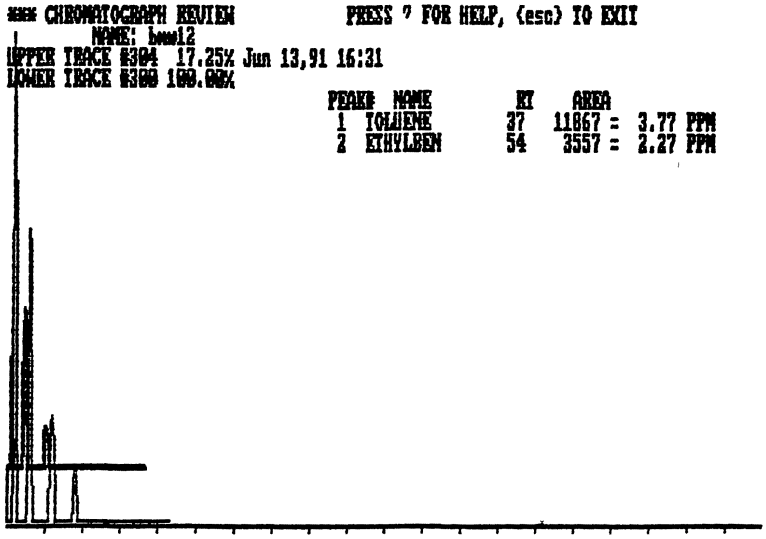
34

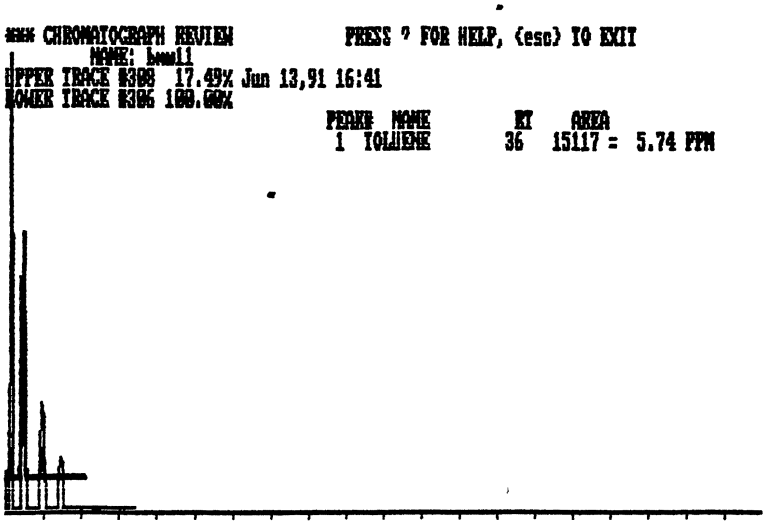
[redacted]

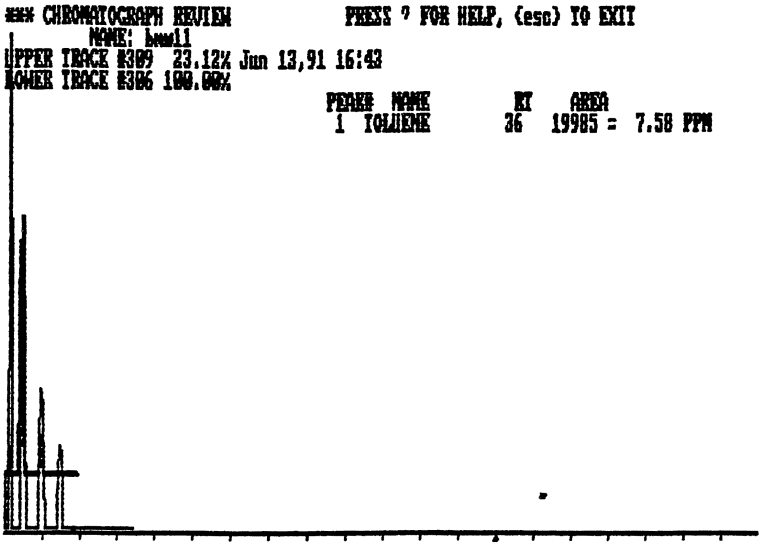
RUN	GAIN	SAMPLE ID	PEAK	RT	CONC	SAMPLE SIZE	
303	15	BMW 12	T	37	6.72 ppm	100 ml	
			E	54	3.83		
			B	Did not call			
304	15	BMW 12	B	Did not call	<1 ppm	100 ml	1.43 E
			T	37	3.77 ppm	avg. 4.86	T
			E	54	2.27 ppm	avg. 3.08	E
305	15	BTEX Std	B			100 ml	
		Bad calib. - ran wrong sample	T				
			E				
			X				
306	15	BTEX Std	B	27	10.81 ppm	100 ml	
			T	36	10.89		
			E	51	11.24		
			X	66	11.44		
307	15	BMW11	B	Did not call	<1 ppm	100 ml	80% air 20% sample
			T	36	3.64		
			E	Did not call			
good → 308	15	BMW11	B		<1		
			T	36	5.74 ppm	=23	
			E		<1 / 25		
good → 309	15	BMW11	B		<1		
			T	36	7.58 ppm	=30	
			E		<1 / .25		
good → 310	15	BMW11	T	36	6.33 ppm	=25	
			E		<1 / .25		

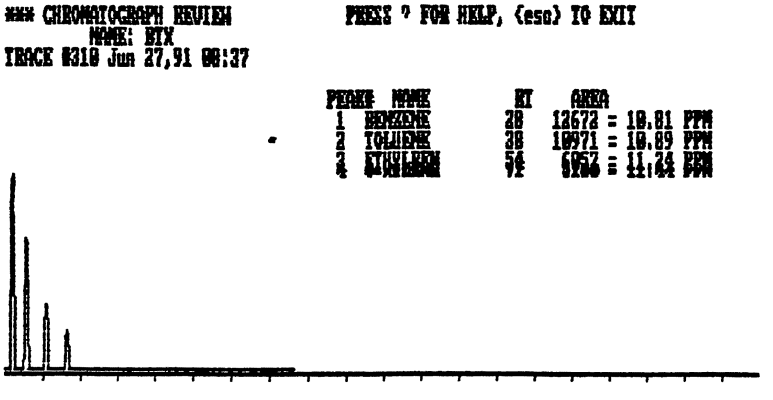
avg = 26 T trc B
6/13/91 trc E

Roy K Wedemann


**** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmul2
UPPER TRACE #304 17.25% Jun 13,91 16:31
LOWER TRACE #300 100.00%
PEAK# NAME RT AREA
1 TOLUENE 37 11867 = 3.77 PPM
2 ETHYLBEN 54 3557 = 2.27 PPM


**** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmul1
UPPER TRACE #300 17.49% Jun 13,91 16:41
LOWER TRACE #306 100.00%
PEAK# NAME RT AREA
1 TOLUENE 36 15117 = 5.74 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: bmw11
UPPER TRACE #309 23.12% Jun 13,91 16:43
LOWER TRACE #306 100.00%
PEAK# NAME RT AREA
1 TOLUENE 36 19985 = 7.58 PPM


*** CHROMATOGRAPH REVIEW PRESS ? FOR HELP, (esc) TO EXIT
NAME: BTX
TRACE #310 Jun 27,91 00:37
PEAK# NAME RT AREA
1 BENZENE 28 12672 = 10.81 PPM
2 TOLUENE 38 19971 = 10.89 PPM

LNS ENVIRONMENTAL SERVICES, INC.

903 North Bowser, Suite 230
Richardson, Texas 75081
(214) 699-3772 Toll Free: 1-800-422-9421

Laboratory Analysis and
Field Consultation
Fax: 214-669-3575

[redacted]

DATE RECEIVED: 05/01/91

DATE ANALYZED: 05/03/91
DATE REPORTED: 05/06/91
REPORT NUMBER: 0450-5

SAMPLE ID: BMW14 (wtr)

AROMATIC VOLATILE ORGANICS BY GC/MS

PARAMETERS	DETECTION LIMIT ug/l	RESULTS ug/l	ANALYST
Benzene	0.20	1.44	GK
Chlorobenzene	0.20	<0.20	GK
1,4-Dichlorobenzene	0.30	<0.30	GK
1,3-Dichlorobenzene	0.40	<0.40	GK
1,2-Dichlorobenzene	0.40	<0.40	GK
Ethyl benzene	0.20	14.28	GK
Toluene	0.20	15.33	GK
Xylenes	0.20	88.31	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC.

D#91/01:0450-5TP.DOC

QUANT REPORT

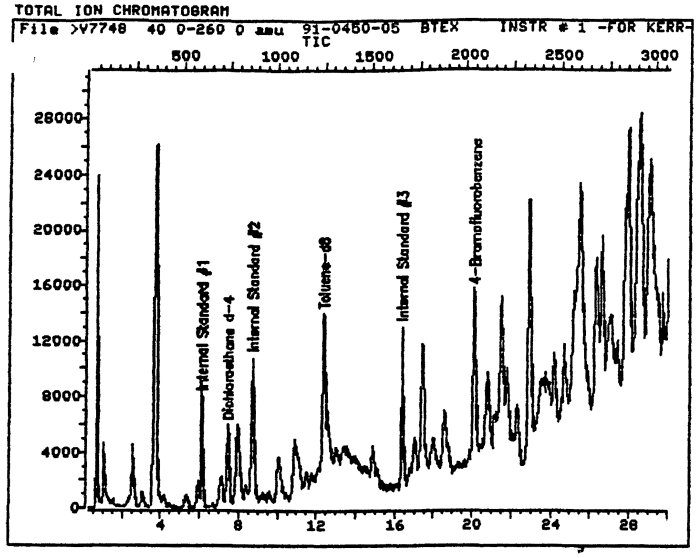
ɹrator ID GEORGE Quant Rev 6 Quant Time 910502 20 56
Output File ^V7748 QO Injected at 910502 20 25
Data File >V7748 V3 Dilution Factor 1.00000
Name 91-0450-05 BTEX
Misc INSTR # 1 [redacted]

ID File IDV0A9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910502 11 08

	Compound	R T	Q ion		Area	Conc	Units	q
1)	*Bromochloromethane	6 07	128	0	10035M	50 00	UG/L	
8)	Acetone	2 49	43	0	21242	399 86	UG/L	100
10)	1,1-Dichloroethene	2 27	96	0	680	2.60	UG/L	88
12)	1,2-Dichloroethene (trans)	2 27	96	0	680	2.51	UG/L	91
14)	1,2-Dichloroethane-d4 *****	7 41	65	0	17952	53 03	UG/L	96
15)	1,2-Dichloroethane	8 70	62	0	637	1 48	UG/L	75
16)	*1,4-Difluorobenzene	8 70	114	0	37673	50 00	UG/L	100
17)	2-Butanone (MEK)	5 86	43	0	12264	131 62	UG/L	93
18)	1,1,1-Trichloroethane	6 58	97	0	227	40	UG/L	96
23)	cis-1,3-Dichloropropene	12 88	75	0	201	47	UG/L	80
28)	Benzene	7 47	78	0	803M	1 44	UG/L	100
29)	trans-1,3-Dichloropropene	13 49	75	0	268	1.76	UG/L	100
31)	*Chlorobenzene-d5	16 35	117	0	31184	50 00	UG/L	96
	4-Methyl-2-Pentanone (MIBK)	12 45	*43	0	3791	28 84	UG/L	94
33)	2-Hexanone	16 02	43	0	324	3 85	UG/L	87
36)	Toluene	12 56	92	0	6132M	15 33	UG/L	92
37)	Toluene-d8 ********	12 35	98	0	38382	64 04	UG/L	96
39)	Ethylbenzene	17 02	106	0	3393M	14 28	UG/L	85
40)	Styrene	20 04	104	0	242	52	UG/L	71
41)	XYLENE (TOTAL)	17 37	106	0	24469M	88.31	UG/L	
42)	Bromofluorobenzene ********	20 09	95	0	23455	56.88	UG/L	92
44)	1,4 - ~~DICHLOROBENZENE~~	~~22 79~~	~~146~~	0	~~141~~	~~24~~	UG/L	86
45)	1,2 - ~~DICHLOROBENZENE~~	~~24 06~~	~~146~~	0	~~374~~	~~69~~	UG/L	76

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File >V7748 V3 Quant Output File ^V7748 QO
Name 91-0450-05 BTEX
Misc INSTR # 1 -FOR [redacted]

Id File IDV0A9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910502 11 08

Operator ID GEORGE
Quant Time 910502 20 56
Injected at 910502 20 25

LNS ENVIRONMENTAL SERVICES, INC.

903 North Bowser, Suite 230
Richardson, Texas 75081
(214) 699-3772 Toll Free 1-800-422-9421

Laboratory Analysis and
Field Consultation
Fax 214-669-3575

[redacted]

DATE RECEIVED: 05/01/91

DATE ANALYZED: 05/03/91
DATE REPORTED: 05/06/91
REPORT NUMBER: 0450-6

SAMPLE ID: BMW22 (wtr)

AROMATIC VOLATILE ORGANICS BY GC/MS

PARAMETERS	DETECTION LIMIT ug/l	RESULTS ug/l	ANALYST
Benzene	0.20	18093.00	GK
Chlorobenzene	0.20	<0.20	GK
1,4-Dichlorobenzene	0.30	<0.30	GK
1,3-Dichlorobenzene	0.40	<0.40	GK
1,2-Dichlorobenzene	0.40	<0.40	GK
Ethyl benzene	0.20	1231.00	GK
Toluene	0.20	11140.00	GK
Xylenes	0.20	6033.00	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC.

QUANT REPORT

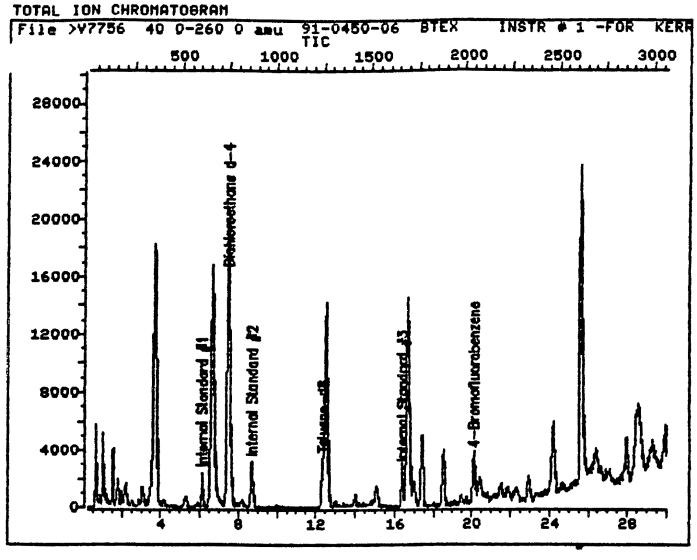
erator ID GEORGE Quant Rev 6 Quant Time 910503 13 43
Output File ^U7756 QO Injected at 910503 13 13
Data File >U7756 V4 Dilution Factor 1 00000
Name 91-0450-06 BTEX
Misc INSTR # 1 - [redacted] DIL 1 50

ID File IDV0A9 .QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910503 12 53

	Compound	R T	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 10	128 0	2711	50 00	UG/L	85
2)	Chloromethane	1 00	50 0	259	104 27	UG/L	95
8)	Acetone	1 51	43 0	4526	98 86	UG/L	100
14)	1,2-Dichloroethane-d4 *****	7 43	65 0	5966	62 16	UG/L	99
15)	1,2-Dichloroethane	7 59	62 0	4086	38 80	UG/L	96
16)	*1,4-Difluorobenzene	8 68	114 0	12626	50 00	UG/L	100
28)	Benzene	7 48	78 0	73955	361 86	UG/L	100
29)	trans-1,3-Dichloropropene	12 50	75 0	469	7 74	UG/L	100
31)	*Chlorobenzene-d5	16 36	117 0	9339	50 00	UG/L	93
32)	4-Methyl-2-Pentanone (MIBK)	12 40	43 0	1305	18 55	UG/L	85
36)	Toluene	12 49	92 0	31148	222 79	UG/L	96
37)	Toluene-d8 ********	12 33	98 0	11820	51 07	UG/L	94
39)	Ethylbenzene	16 97	106 0	2000	24 61	UG/L	96
	XYLENE (TOTAL)	17 36	106 0	10989M	120 65	UG/L	94
42)	Bromofluorobenzene ********	20 08	95 0	6848	51 12	UG/L	92

* Compound is ISTD

(28) 18093 ug/L ✓
(36) 11140 ug/L ✓
(39) 1231 ug/L ✓
(41) 6033 ug/L ✓



Data File >V7756 V4 Quant Output File ^V7756 QO
Name 91-0450-06 BTEX
Misc INSTR # 1 -FOR [redacted] DIL 1 50

Id File IDV0A9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910503 12 53

Operator ID GEORGE
Quant Time 910503 13 43
Injected at 910503 13 13

LNS ENVIRONMENTAL SERVICES, INC.

903 North Bowser, Suite 230
Richardson, Texas 75081
(214) 699-3772 Toll Free: 1-800-422-9421

Laboratory Analysis and
Field Consultation
Fax: 214-669-3575

[redacted]

DATE RECEIVED: 05/01/91

DATE ANALYZED: 05/02/91
DATE REPORTED: 05/06/91
REPORT NUMBER: 0450-4

SAMPLE ID: SVP1 (soil)

AROMATIC VOLATILE ORGANICS BY GC/MS

PARAMETERS	DETECTION LIMIT ug/kg	RESULTS ug/kg	ANALYST
Benzene	5	798	GK
Chlorobenzene	5	13	GK
1,4-Dichlorobenzene	5	<5	GK
1,3-Dichlorobenzene	5	<5	GK
1,2-Dichlorobenzene	5	<5	GK
Ethyl benzene	5	943	GK
Toluene	5	3275	GK
Xylenes	5	5676	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC.

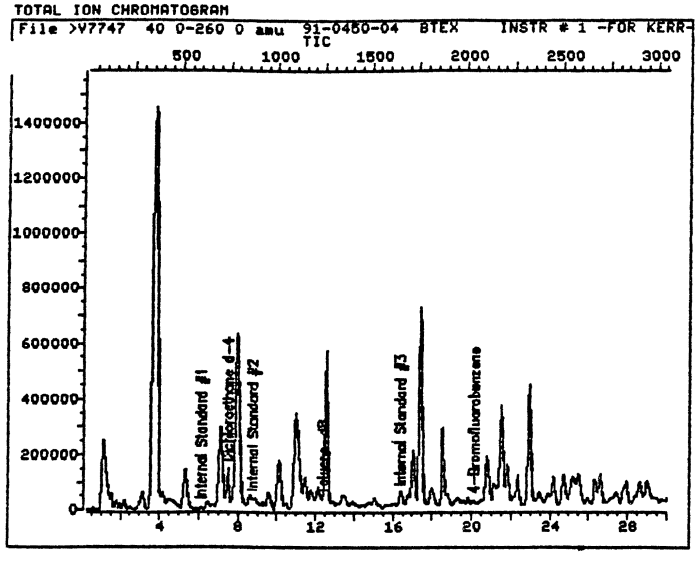
QUANT REPORT

ɾ ɹrator ID GEORGE Quant Rev 6 Quant Time 910502 20 22
Output File ^V7747 QD Injected at 910502 19:51
Data File >V7747 V3 Dilution Factor 1.00000
Name 91-0450-04 BTEX
Misc INSTR # 1 - [redacted] SOIL 5 GMS/5MLS

ID File IDV0A9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910502 11 08

	Compound	R T	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 10	128 0	9425M	50 00	UG/L	
2)	Chloromethane	1 96	50 0	1225	62 85	UG/L	97
4)	Vinyl Chloride	5 28	62.0	808	18 06	UG/L	87
8)	Acetone	2.46	43 0	52366	1049 54	UG/L	100
9)	Carbon Disulfide	3 69	76.0	960	2 12	UG/L	100
14)	1,2-Dichloroethane-d4 *****	7 45	65 0	16456	51 76	UG/L	95
15)	1,2-Dichloroethane	7 62	62 0	6779	16 79	UG/L	91
16)	*1,4-Difluorobenzene	8 74	114 0	38122	50 00	UG/L	100
17)	2-Butanone (MEK)	5 86	43 0	17439	184 95	UG/L	93
18)	1,1,1-Trichloroethane	6 65	97 0	417	72	UG/L	88
20)	Vinyl Acetate	3 13	43 0	225257	5874 36	UG/L	66
21)	Bromodichloromethane	10 44	83 0	1241	2 40	UG/L	84
22)	1,2-Dichloropropane	8 73	63 0	11082	48 54	UG/L	74
	cis-1,3-Dichloropropene	12 34	75 0	127	.29	UG/L	85
28)	Benzene	7 49	78 0	450467	797 82	UG/L	100
29)	trans-1,3-Dichloropropene	13 49	75 0	136	88	UG/L	100
31)	*Chlorobenzene-d5	16 36	117 0	27794	50.00	UG/L	90
32)	4-Methyl-2-Pentanone (MIBK)	12 54	43 0	51283	437 79	UG/L	87
36)	Toluene	12 56	92.0	1167553	3275 31	UG/L	94
37)	Toluene-d8 ********	12 36	98 0	42690	79 92	UG/L	95
38)	Chlorobenzene	17 90	112 0	6696	13 49	UG/L	77
39)	Ethylbenzene	17 00	106 0	199764	943 12	UG/L	99
41)	XYLENE (TOTAL) *	17 42	106 0	1401775M	5675 85	UG/L	93
42)	Bromofluorobenzene ********	20 11	95 0	17886	48 67	UG/L	84

* Compound is ISTD



Data File >V7747 V3 Quant Output File ^V7747 QO
Name 91-0450-04 BTEX
Misc INSTR # 1 -FOR[redacted] SOIL 5 GMS/5MLS

Id File IDVOA9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910502 11 08

Operator ID GEORGE
Quant Time 910502 20 22
Injected at 910502 19 51

LNS ENVIRONMENTAL SERVICES, INC.

903 North Bowser, Suite 230
Richardson, Texas 75081
(214) 699-3772 Toll Free 1-800-422-9421

Laboratory Analysis and
Field Consultation
Fax 214-669-3575

[redacted]

SAMPLE ID: SVP2 (soil)

DATE RECEIVED: 05/01/91

DATE ANALYZED: 05/02/91
DATE REPORTED: 05/06/91
REPORT NUMBER: 0450-2

AROMATIC VOLATILE ORGANICS BY GC/MS

PARAMETERS	DETECTION LIMIT ug/kg	RESULTS ug/kg	ANALYST
Benzene	5	276	GK
Chlorobenzene	5	44	GK
1,4-Dichlorobenzene	5	<5	GK
1,3-Dichlorobenzene	5	<5	GK
1,2-Dichlorobenzene	5	<5	GK
Ethyl benzene	5	5644	GK
Toluene	5	13668	GK
Xylenes	5	27819	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC.

QUANT REPORT

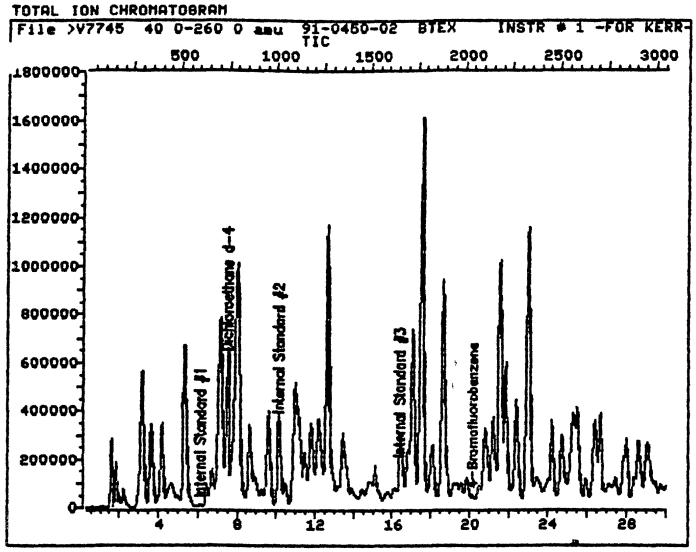
Operator ID GEORGE Quant Rev 6 Qu 16
Output File ^U7745 QD Inj .45
Data File >U7745 U3 Dilutio 1000
Name 91-0450-02 BTEX
Misc INSTR # 1 [redacted] SOIL 5 GMS/5MLS

ID File IDVOA9:*QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910502 11 08

	Compound	R T	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 10	128 0	8031	50 00	UG/L	83
2)	Chloromethane	1 52	50 0	15739	947 67	UG/L	98
4)	Vinyl Chloride	3 58	62 0	2226	58 40	UG/L	80
5)	Chloroethane	3.11	64 0	489	7 32	UG/L	82
8)	Acetone	3 16	43 0	1995961	46947 77	UG/L	100
10)	1,1-Dichloroethene	2 29	96 0	478	2 28	UG/L	83
11)	1,1-Dichloroethane	6 15	63 0	142	33	UG/L	94
12)	1,2-Dichloroethene (trans)	2 29	96 0	478	2 21	UG/L	78
13)	Chloroform	4 67	83 0	437	76	UG/L	98
14)	1,2-Dichloroethane-d4 *****	7 46	65 0	14399	53 15	UG/L	91
15)	1,2-Dichloroethane	7 63	62 0	79510	231 05	UG/L	97
16)	*1,4-Difluorobenzene	10 10	114 0	36857	50 00	UG/L	100
17)	2-Butanone (MEK)	7 08	43 0	2200401	24137 68	UG/L	59
	1,1,1-Trichloroethane	6 65	97 0	655	1.17	UG/L	79
20)	Vinyl Acetate	5.38	43 0	781703	21085 29	UG/L	58
23)	cis-1,3-Dichloropropene	14 41	75 0	288	.69	UG/L	80
26)	Dibromochloromethane	16.01	129 0	251	58	UG/L	97
28)	Benzene	7 52	78 0	1509011M	2764 34	UG/L	100
29)	trans-1,3-Dichloropropene	14 96	75 0	191	1 28	UG/L	100
31)	*Chlorobenzene-d5	16 35	117 0	22036M	50 00	UG/L	
32)	4-Methyl-2-Pentanone (MIBK)	12 61	43 0	79660	857 73	UG/L	74
36)	Toluene	12 63	92 0	3862973M	13668 32	UG/L	80
38)	Chlorobenzene	16 45	112.0	17498	44 46	UG/L	71
39)	Ethylbenzene	17 04	106 0	947883	5644 44	UG/L	88
41)	XYLENE (TOTAL)	17 52	106 0	5447085M	27818 59	UG/L	92
42)	Bromofluorobenzene ********	20 13	95 0	16952	58 18	UG/L	94
44)	1,4 - DICHLOROBENZENE	24 31	146 0	117	28	UG/L	88

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File >V7745 V3 Quant Output File ^V7745 QO
Name 91-0450-02 BTEX
Misc: INSTR # 1 - [redacted] SOIL 5 GMS/5MLS

Id File IDV0A9 .QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910502 11 08

Operator ID GEORGE
Quant Time 910502 19 16
Injected at 910502 18 45

LNS ENVIRONMENTAL SERVICES, INC.

903 North Bowser, Suite 230
Richardson, Texas 75081
(214) 699-3772 Toll Free: 1-800-422-9421

Laboratory Analysis and
Field Consultation
Fax: 214-669-3575

[redacted]

DATE RECEIVED: 05/01/91

DATE ANALYZED: 05/02/91
DATE REPORTED: 05/06/91
REPORT NUMBER: 0450-3

SAMPLE ID: SVP3 (soil)

AROMATIC VOLATILE ORGANICS BY GC/MS

PARAMETERS	DETECTION LIMIT ug/kg	RESULTS ug/kg	ANALYST
Benzene	5	19	GK
Chlorobenzene	5	<5	GK
1,4-Dichlorobenzene	5	<5	GK
1,3-Dichlorobenzene	5	<5	GK
1,2-Dichlorobenzene	5	<5	GK
Ethyl benzene	5	75	GK
Toluene	5	90	GK
Xylenes	5	666	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC.

QUANT REPORT

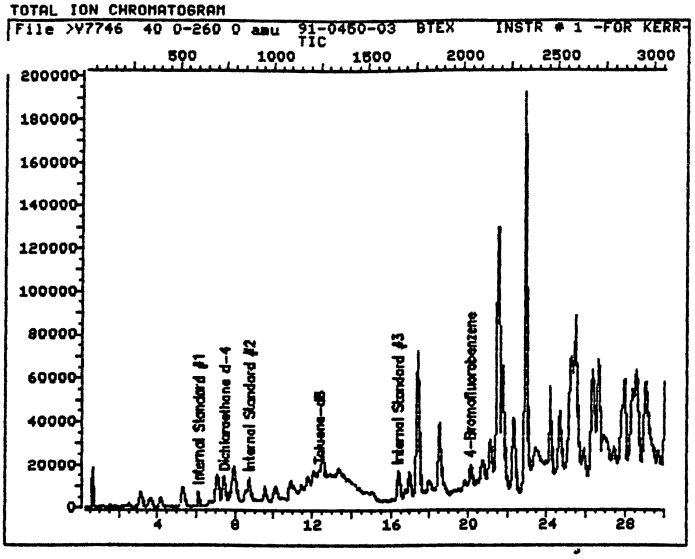
L ..rator ID GEORGE Quant Rev 6 Quant Time 910502 19 49
Output File ^V7746 Q0 Injected at 910502 19 18
Data File >V7746 V3 Dilution Factor 1 00000
Name 91-0450-03 BTEX
Misc INSTR # 1 [redacted] SOIL 5 GMS/5MLS

ID File IDV0A9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910502 11 08

	Compound	R T	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 09	128 0	8719	50 00	UG/L	85
7)	Trichlorofluoromethane	2 38	101 0	1778	3 09	UG/L	89
8)	Acetone	2 48	43 0	8593	186 17	UG/L	100
10)	1,1-Dichloroethene	2 29	96 0	644	2 83	UG/L	86
12)	1,2-Dichloroethene (trans)	2 29	96 0	644	2 74	UG/L	86
14)	1,2-Dichloroethane-d4 *****	7 43	65 0	16476	56 01	UG/L	94
16)	*1,4-Difluorobenzene	8 70	114 0	36202	50 00	UG/L	100
17)	2-Butanone (MEK)	5 84	43 0	3038	33 93	UG/L	88
18)	1,1,1-Trichloroethane	6 60	97 0	954	1 74	UG/L	73
20)	Vinyl Acetate	3 55	43 0	1052	28 89	UG/L	88
22)	1,2-Dichloropropane	9 47	63 0	250	1 15	UG/L	95
23)	cis-1,3-Dichloropropene	10 64	75 0*	169	41	UG/L	93
28)	Benzene	7 48	78 0	10390	19 38	UG/L	100
	trans-1,3-Dichloropropene	12 44	75 0	132	90	UG/L	100
31)	*Chlorobenzene-d5	16 36	117 0	25344	50 00	UG/L	99
32)	4-Methyl-2-Pentanone (MIBK)	12 35	43 0	226	2 12	UG/L	95
36)	Toluene	12 50	92 0	29154	89 69	UG/L	96
37)	Toluene-d8 ********	12 34	98 0	17752	36 45	UG/L	95
39)	Ethylbenzene	16 96	106 0	14542	75 29	UG/L	95
40)	Styrene	19 47	104 0	336	89	UG/L	86
41)	XYLENE (TOTAL)	17 36	106 0	150087M	666 46	UG/L	93
42)	Bromofluorobenzene ********	20 08	95 0	18536	55 31	UG/L	92
44)	1,4 - DICHLOROBENZENE	22 25	146 0	141	29	UG/L	94

* Compound is ISTD

TOTAL ION CHROMATOGRAM



Data File >V7746 V3 Quant Output File ^V7746 QO
Name 91-0450-03 BTEX
Misc INSTR # 1 [redacted] SOIL 5 GMS/5MLS

Id File IDV0A9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910502 11 08

Operator ID GEORGE
Quant Time 910502 19 49
Injected at 910502 19 18

LNS ENVIRONMENTAL SERVICES, INC.

903 North Bowser, Suite 230
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(214) 699-3772 Toll Free: 1-800-422-9421

Laboratory Analysis and
Field Consultation
Fax: 214-669-3575

[redacted]

DATE RECEIVED: 05/01/91

DATE ANALYZED: 05/03/91
DATE REPORTED: 05/06/91
REPORT NUMBER: 0450-1

SAMPLE ID: SVP4 (soil)

AROMATIC VOLATILE ORGANICS BY GC/MS

PARAMETERS	DETECTION LIMIT ug/kg	RESULTS ug/kg	ANALYST
Benzene	5	1630	GK
Chlorobenzene	5	99	GK
1,4-Dichlorobenzene	5	<5	GK
1,3-Dichlorobenzene	5	<5	GK
1,2-Dichlorobenzene	5	<5	GK
Ethyl benzene	5	17629	GK
Toluene	5	42872	GK
Xylenes	5	107559	GK

Niranjan Shah
LNS ENVIRONMENTAL SERVICES, INC.

D/91/01:0450-1TP.DOC

QUANT REPORT

Operator ID GEORGE Quant Rev 6 Quant Time 910503 14 21
Output File ^V7757 ·QO Injected at 910503 13 50
Data File >V7757 V4 Dilution Factor 5 00000
Name 91-0450-01 BTEX
Misc INSTR # 1 -FOR [redacted] SOIL 1 GMS/5 MLS

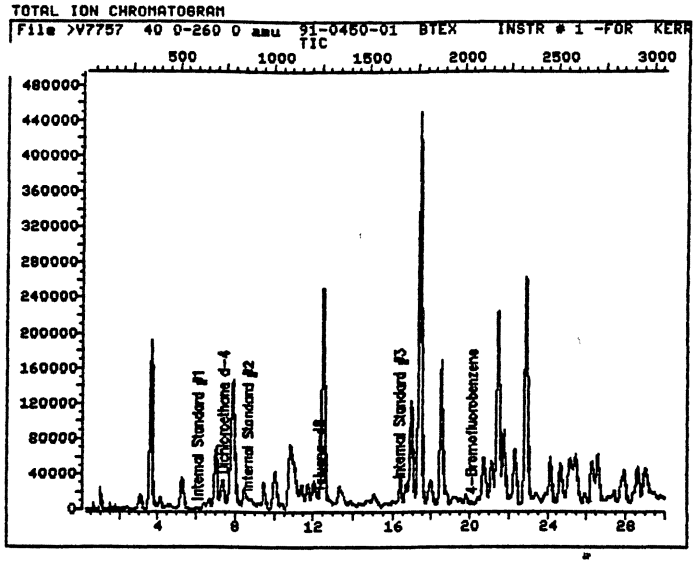
ID File IDV0A9· QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910503 12 53

	Compound	R T	Q ion	Area	Conc	Units	q
1)	*Bromochloromethane	6 06	128 0	2942	50.00	UG/L	93
2)	Chloromethane	99	50 0	5638	10458 06	UG/L	72
7)	Trichlorofluoromethane	2 38	101 0	6883	224 81	UG/L	94
8)	Acetone	3 09	43 0	53600	5394 35	UG/L	100
13)	Chloroform	6.38	83 0	179	4 65	UG/L	77
14)	1,2-Dichloroethane-d4 *****	7 38	65 0	6357	305 19	UG/L	93
15)	1,2-Dichloroethane	7.55	62 0	2156	94 34	UG/L	92
16)	*1,4-Difluorobenzene	8 65	114 0	12768	50 00	UG/L	100
17)	2-Butanone (MEK)	6 99	43 0	163516	10968 44	UG/L	59
18)	1,1,1-Trichloroethane	6 58	97 0	809	20 64	UG/L	71
20)	Vinyl Acetate	4 12	43 0	19994	9808 01	UG/L	70
21)	Bromodichloromethane	10 40	83 0	167	4 83	UG/L	96
22)	1,2-Dichloropropane	11 14	63 0	128	8 14	UG/L	94
	1,1,2-Trichloroethane	11 90	97 0	154	9 36	UG/L	98
26)	Benzene	7 42	78 0	67391	1630 40	UG/L	100
29)	trans-1,3-Dichloropropene	12 49	75 0	6851	559 34	UG/L	100
31)	*Chlorobenzene-d5	16 30	117 0	4146	50.00	UG/L	83
32)	4-Methyl-2-Pentanone (MIBK)	12 48	43 0	17091	2735 85	UG/L	75
36)	Toluene	12 47	92 0	532177	42871 09	UG/L	97
37)	Toluene-d8 ********	12 30	98 0	13748	668.96	UG/L	97
38)	Chlorobenzene	16 37	112 0	1634	98 78	UG/L	71
39)	Ethylbenzene	16 95	106 0	127182	17628 79	UG/L	99
41)	XYLENE (TOTAL) *	17 35	106 0	869838M	107559 0	UG/L	95
42)	Bromofluorobenzene ********	20 08	95 0	6217	522 65	UG/L	93

* Compound is ISTD

Btx/ w/ X

TOTAL ION CHROMATOGRAM



Data File >V7757 ·V4 Quant Output File ^V7757 QO
Name 91-0450-01 BTEX
Misc INSTR # 1 -FOR [redacted] SOIL 1 GMS/5 MLS

Id File. IDVOA9 QT
Title Daily Cal via Single Point at 50 ug/L 30M DB-624
Last Calibration 910503 12 53

Operator ID GEORGE
Quant Time 910503 14 21
Injected at 910503 13 50

SHIPPING DOCUMENT # KK0001

KERR-McGEE CORPORATION

CHAIN OF CUSTODY RECORD — ENVIRONMENTAL SAMPLES KM-4778

FACILITY	SAMPLING FIRM	SAMPLE
NAME [redacted] BLT	NAME [redacted]	☐ Effluent ☒ Groundwater
ADDRESS [redacted]	ADDRESS [redacted]	☒ Solid ☐ Surface Water
[redacted]	SIGNATURE Tim Bent	☐

NO	LOCATION	DATE	TIME	WEATHER TEMP	WEATHER PREC	SAMPLE TYPE AND METHOD COMP	GRAB	MECH	MAN	TIMES CASING CLEARED	NO OF CONTAINERS	ANALYSIS REQUIRED	REMARKS
1	SVP3 (soil)	4-30-91	11:00	68°	NA		X				1-40 ml.	TPH by Method	Please
2	SVP2 (soil)	"	11:30				X				"	8020 "	include all
3	SVP 1 (soil)	"	12:30				X				"	"	chromatograms
4	SVP4 (soil)	"	13:00				X				"	"	with analyses
5	BMW14 (wtr)	"	14:00				X			3	1-1l	"	results
6	BMW22 (wtr)	"	14:15				X			3	"	"	

RELINQUISHED BY (SIGNATURE) Tim Bent 4-30-91	RECEIVED BY (SIGNATURE)	DATE	TIME
RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME
RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME
DISPATCHED BY (SIGNATURE) DATE TIME	RECEIVED FOR LABORATORY (SIGNATURE)	DATE	TIME

ADDITIONAL REMARKS

CARRIER Federal Express	LABORATORY LNS Environmental Services, Inc.
ADDRESS OKC, OK	ADDRESS 903 North Bowser, Suite 230
METHOD OF SHIPMENT overnight	Richardson, TX 75081

ALL ANALYSIS PERFORMED BY EPA APPROVED PROCEDURES

☐ Yes ☐ No explain above

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. Albany • Suite "C" • Broken Arrow, Oklahoma 74012 • 918-251-2858 • FAX: 918-251-2599

CLIENT: [redacted]

REPORT: 4851.08VS

DATE: 02-06-91

SAMPLE MATRIX: WATER
SWLO # 4851.08
DATE SUBMITTED: 01-21-91
DATE ANALYZED : 01-23-91
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: BMW12

SKINNER'S LIST

RESULTS REPORTED IN ug/l OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	5	16328
CARBON DISULFIDE	5	ND
CHLOROBENZENE	5	ND
CHLOROFORM	5	208 BJ
1,2 DICHLOROETHANE	5	1795
1,4 DIOXANE	5	ND
ETHYL BENZENE	5	120 J
ETHYLENE DIBROMIDE	5	ND
METHYL ETHYL KETONE	5	ND
STYRENE	5	ND
TOLUENE	5	4201
XYLENE	5	811

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 100% BROMOFLUOROBENZENE(86-115) 94% 1,2-DICHLOROETHANE-d4(76-114) 94%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow, Oklahoma 74012 • 918-251-2858

CLIENT: [redacted]
OKLAHOMA CITY, OKLAHOMA 73125
ATTN: [redacted]

REPORT: 2917.01SV
DATE: 07-10-90

SAMPLE MATRIX: WATER
SWLO # 2917.01
DATE SUBMITTED: 06-23-90
DATE SAMPLED: 06-22-90
DATE ANALYZED : 06-26-90
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: BMW19

SKINNER'S LIST

RESULTS REPORTED IN ug/L OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	5	ND
CARBON DISULFIDE	5	ND
CHLOROBENZENE	5	ND
CHLOROFORM	5	1 JB
1,2 DICHLOROETHANE	5	ND
1,4 DIOXANE	5	ND
ETHYL BENZENE	5	ND
ETHYLENE DIBROMIDE	5	ND
METHYL ETHYL KETONE	5	ND
STYRENE	5	ND
TOLUENE	5	ND
XYLENE	5	ND

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 98% BROMOFLUOROBENZENE(86-115) 97% 1,2-DICHLOROETHANE-d4(76-114) 89%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow Oklahoma 74012 • 918 251 2858 • FAX 918 251 2599

CLIENT: [redacted]

REPORT: 4851.07VS

DATE: 02-06-91

SAMPLE MATRIX: WATER
SWLO # 4851.07
DATE SUBMITTED: 01-21-91
DATE ANALYZED : 01-23-91
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: BMW20

SKINNER'S LIST

RESULTS REPORTED IN ug/l OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	5	ND
CARBON DISULFIDE	5	ND
CHLOROBENZENE	5	ND
CHLOROFORM	5	ND
1,2 DICHLOROETHANE	5	ND
1,4 DIOXANE	5	ND
ETHYL BENZENE	5	ND
ETHYLENE DIBROMIDE	5	ND
METHYL ETHYL KETONE	5	ND
STYRENE	5	ND
TOLUENE	5	ND
XYLENE	5	ND

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 101% BROMOFLUOROBENZENE(86-115) 95% 1,2-DICHLOROETHANE-d4(76-114) 91%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow, Oklahoma 74012 • 918-251-2858

CLIENT: [redacted]

REPORT: 3245.01BX

DATE: 08-06-90

SAMPLE MATRIX: WATER
SWLO # 3245.01
DATE SAMPLED: 07-25-90
DATE SUBMITTED: 07-27-90
PROJECT: [redacted]
SAMPLE ID: BRW2

PARAMETER	DET. LIMIT	UNIT	RESULTS	DATE ANALYZED	METHOD REFERENCE
GAS CHROMATOGRAPHY					
BENZENE	100	ug/L	4050	08-01-90	SW 8240
TOLUENE	100	ug/L	1530	08-01-90	SW 8240
ETHYLBENZENE	100	ug/L	118	08-01-90	SW 8240
XYLENES	100	ug/L	947	08-01-90	SW 8240

QA/QC SURROGATE RECOVERIES

4-BROMOFLUOROBENZENE (65-135%) 88%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS ON ORIGINAL RUN AND RERUN.
SW = TEST METHODS FOR EVALUATING SOLID WASTE, EPA PUBLICATION #SW846, THIRD EDITION, NOVEMBER 1986

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow, Oklahoma 74012 • 918-251-2858

CLIENT: [redacted]

REPORT: 3079.01SV

DATE: 07-17-90

SAMPLE MATRIX: WATER
SWLO # 3079.01
DATE SAMPLED : 07-11-90
DATE SUBMITTED: 07-12-90
DATE ANALYZED : 07-16-90
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
SAMPLE ID: BMW 20 WELL

SKINNER'S LIST

RESULTS REPORTED IN ug/L OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	5	ND
CARBON DISULFIDE	5	ND
CHLOROBENZENE	5	ND
CHLOROFORM	5	ND
1,2 DICHLOROETHANE	5	ND
1,4 DIOXANE	5	ND
ETHYL BENZENE	5	ND
ETHYLENE DIBROMIDE	5	ND
METHYL ETHYL KETONE	5	ND
STYRENE	5	ND
TOLUENE	5	ND
XYLENE	5	ND

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 98% BROMOFLUOROBENZENE(86-115) 93% 1,2-DICHLOROETHANE-d4(76-114) 91%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
= ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
= ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow, Oklahoma 74012 • 918-251-2858

CLIENT: [redacted]
ATTN: [redacted]

REPORT: 2935.02SB
DATE: 07-17-90

SAMPLE MATRIX: WATER
SWLO # 2935.02
METHOD REFERENCE: SW846-8270, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: BMW 20 WELL

DATE SUBMITTED: 06-22-90
DATE EXTRACTED: 06-26-90
DATE ANALYZED: 07-03-90

SKINNER'S LIST

RESULTS REPORTED IN ug/L OR Parts Per Billion (PPB)

BASE/NEUTRAL EXTRACTABLES	DET. LIMIT	RESULTS	ACID EXTRACTABLE COMPOUNDS	DET. LIMIT	RESULTS
ANTHRACENE	10	ND	BENZENETHIOL	10	ND
BENZO(A) ANTHRACENE	10	ND	CRESOL (ORTHO)	10	ND
BENZO(B) FLUORANTHENE	10	ND	CRESOL (PARA)	10	ND
BENZO(K) FLUORANTHENE	10	ND	2,4-DIMETHYLPHENOL	10	ND
BENZO(A) PYRENE	10	ND	2,4-DINITROPHENOL	50	ND
BIS(2-ETHYLHEXYL) PHTHALATE	10	ND	4-NITROPHENOL	50	ND
BUTYL BENZYL PHTHALATE	10	ND	PHENOL	10	ND
CHRYSENE	10	ND			
DIBENZ(A,H) ACRIDINE	10	ND			
DIBENZ(A,H) ANTHRACENE	10	ND			
,2-DICHLOROBENZENE	10	ND			
1,3-DICHLOROBENZENE	10	ND			
1,4-DICHLOROBENZENE	10	ND			
DIETHYL PHTHALATE	10	ND			
7,12-DIMETHYLBENZ(A)ANTHRACENE	10	ND			
DIMETHYL PHTHALATE	10	ND			
DI(N)BUTYL PHTHALATE	10	ND			
DI(N)OCTYL PHTHALATE	10	ND			
FLUORANTHENE	10	ND			
INDENE	10	ND			
METHYL CHRYSENE	10	ND			
1-METHYL NAPHTHALENE	10	ND			
NAPHTHALENE	10	ND			
PHENANTHRENE	10	ND			
PYRENE	10	ND			
PYRIDINE	10	ND			
QUINOLINE	10	ND			
2-METHYL NAPTHALENE	10	ND			

QA/QC SURROGATE RECOVERIES

NITROBENZENE-d5	(35-114)	58%	2-FLUOROBIPHENYL	(43-116)	60%	TERPHENYL-d14 (33-141)	59%
PHENOL-d5	(10-94)	56%	2-FLUOROPHENOL	(21-100)	56%	2,4,6-TRIBROMOPHENOL	(10-123) 76%

) = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow, Oklahoma 74012 • 918-251-2858

CLIENT: [redacted]
ATTN: [redacted]

REPORT: 2917.01SB
DATE: 07-10-90

SAMPLE MATRIX: WATER
SWLO # 2917.01
METHOD REFERENCE: SW846-8270, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: BMW19

DATE SUBMITTED: 06-23-90
DATE EXTRACTED: 07-02-90
DATE ANALYZED: 07-06-90

SKINNER'S LIST

RESULTS REPORTED IN ug/L OR Parts Per Billion (PPB)

BASE/NEUTRAL EXTRACTABLES	DET. LIMIT	RESULTS	ACID EXTRACTABLE COMPOUNDS	DET. LIMIT	RESULTS
ANTHRACENE	70	ND	BENZENETHIOL	70	ND
BENZO(A) ANTHRACENE	70	ND	CRESOL (ORTHO)	70	ND
BENZO(B) FLUORANTHENE	70	ND	CRESOL (PARA)	70	ND
BENZO(K) FLUORANTHENE	70	ND	2,4-DIMETHYLPHENOL	350	ND
BENZO(A) PYRENE	70	ND	2,4-DINITROPHENOL	350	ND
BIS(2-ETHYLHEXYL) PHTHALATE	70	ND	4-NITROPHENOL	350	ND
BUTYL BENZYL PHTHALATE	70	ND	PHENOL	70	ND
CHRYSENE	70	ND			
DIBENZ(A,H) ACRIDINE	70	ND			
DIBENZ(A,H) ANTHRACENE	70	ND			
2-DICHLOROBENZENE	70	ND			
1,3-DICHLOROBENZENE	70	ND			
1,4-DICHLOROBENZENE	70	ND			
DIETHYL PHTHALATE	70	ND			
7,12-DIMETHYLBENZ(A)ANTHRACENE	70	ND			
DIMETHYL PHTHALATE	70	ND			
DI(N)BUTYL PHTHALATE	70	ND			
DI(N)OCTYL PHTHALATE	70	ND			
FLUORANTHENE	70	ND			
INDENE	70	ND			
METHYL CHRYSENE	70	ND			
1-METHYL NAPHTHALENE	70	ND			
NAPHTHALENE	70	ND			
PHENANTHRENE	70	ND			
PYRENE	70	ND			
PYRIDINE	70	ND			
QUINOLINE	70	ND			
2-METHYL NAPTHALENE	70	ND			

QA/QC SURROGATE RECOVERIES

NITROBENZENE-d5(35-114)	79%	2-FLUOROBIPHENYL(43-116)	79%	TERPHENYL-d14	(33-141)	82%
PHENOL-d5 (10-94)	41%	2-FLUOROPHENOL (21-100)	35%	2,4,6-TRIBROMOPHENOL	(10-123)	24%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
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B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow Oklahoma 74012 • 918 251 2858 • FAX 918 251 2599

CLIENT: [redacted]

REPORT: 4851.02VS

DATE: 02-06-91

SAMPLE MATRIX: WATER
SWLO # 4851.02
DATE SUBMITTED: 01-21-91
DATE ANALYZED : 01-22-91
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: POND

SKINNER'S LIST

RESULTS REPORTED IN ug/l OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	5	ND
CARBON DISULFIDE	5	ND
CHLOROBENZENE	5	ND
CHLOROFORM	5	ND
1,2 DICHLOROETHANE	5	3 J
1,4 DIOXANE	5	ND
ETHYL BENZENE	5	ND
ETHYLENE DIBROMIDE	5	ND
METHYL ETHYL KETONE	5	ND
STYRENE	5	ND
TOLUENE	5	ND
XYLENE	5	2 J

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 98% BROMOFLUOROBENZENE(86-115) 95% 1,2-DICHLOROETHANE-d4(76-114) 93.

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE. CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow, Oklahoma 74012 • 918-251-2858 • FAX 918-251 2599

CLIENT: [redacted]

REPORT: 4851.06VS

DATE: 02-06-91

SAMPLE MATRIX: WATER
SWLO # 4851.06
DATE SUBMITTED: 01-21-91
DATE ANALYZED : 01-22-91
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: OS5

SKINNER'S LIST

RESULTS REPORTED IN ug/l OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	5	2 J
CARBON DISULFIDE	5	ND
CHLOROBENZENE	5	ND
CHLOROFORM	5	ND
1,2 DICHLOROETHANE	5	ND
1,4 DIOXANE	5	ND
ETHYL BENZENE	5	ND
ETHYLENE DIBROMIDE	5	ND
METHYL ETHYL KETONE	5	ND
STYRENE	5	ND
TOLUENE	5	ND
XYLENE	5	ND

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 102% BROMOFLUOROBENZENE(86-115) 98% 1,2-DICHLOROETHANE-d4(76-114) 97%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow Oklahoma 74012 • 918 251 2858 • FAX 918 251 2599

CLIENT: [redacted]

REPORT: 4851.05VS

DATE. 02-06-91

SAMPLE MATRIX: WATER
SWLO # 4851.05
DATE SUBMITTED: 01-21-91
DATE ANALYZED : 01-22-91
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: OS4

SKINNER'S LIST

RESULTS REPORTED IN ug/l OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	5	ND
CARBON DISULFIDE	5	ND
CHLOROBENZENE	5	ND
CHLOROFORM	5	ND
1,2 DICHLOROETHANE	5	ND
1,4 DIOXANE	5	ND
ETHYL BENZENE	5	ND
ETHYLENE DIBROMIDE	5	ND
METHYL ETHYL KETONE	5	ND
STYRENE	5	ND
TOLUENE	5	ND
XYLENE	5	ND

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 106% BROMOFLUOROBENZENE(86-115) 103% 1,2-DICHLOROETHANE-d4(76-114) 99%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow Oklahoma 74012 • 918 251-2858 • FAX 918-251 2599

CLIENT: [redacted]

REPORT: 4851.03VS

DATE: 02-06-91

SAMPLE MATRIX: WATER
SWLO # 4851.03
DATE SUBMITTED: 01-21-91
DATE ANALYZED : 01-22-91
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: OS2

SKINNER'S LIST

RESULTS REPORTED IN ug/l OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	5	ND
CARBON DISULFIDE	5	ND
CHLOROBENZENE	5	ND
CHLOROFORM	5	ND
1,2 DICHLOROETHANE	5	ND
1,4 DIOXANE	5	ND
ETHYL BENZENE	5	ND
ETHYLENE DIBROMIDE	5	ND
METHYL ETHYL KETONE	5	ND
STYRENE	5	ND
TOLUENE	5	ND
XYLENE	5	ND

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 96% BROMOFLUOROBENZENE(86-115) 91% 1,2-DICHLOROETHANE-d4(76-114) 90%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W Albany • Suite "C" • Broken Arrow Oklahoma 74012 • 918-251 2858 • FAX 918 251 2599

CLIENT: [redacted]

REPORT: 4851.04VS

DATE: 02-06-91

SAMPLE MATRIX: WATER
SWLO # 4851.04
DATE SUBMITTED: 01-21-91
DATE ANALYZED : 01-23-91
METHOD REFERENCE: SW846-8240, EPA METHODOLOGY
PROJECT: [redacted]
SAMPLE ID: OS1

SKINNER'S LIST

RESULTS REPORTED IN ug/l OR Parts Per Billion (PPB)

VOLATILES	DET. LIMIT	RESULTS
BENZENE	50	ND
CARBON DISULFIDE	50	ND
CHLOROBENZENE	50	ND
CHLOROFORM	50	18 BJ
1,2 DICHLOROETHANE	50	149
1,4 DIOXANE	50	ND
ETHYL BENZENE	50	ND
ETHYLENE DIBROMIDE	50	ND
METHYL ETHYL KETONE	50	ND
STYRENE	50	ND
TOLUENE	50	ND
XYLENE	50	ND

QA/QC SURROGATE RECOVERIES

TOLUENE-d8(88-110) 99% BROMOFLUOROBENZENE(86-115) 92% 1,2-DICHLOROETHANE-d4(76-114) 96%

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS

APPENDIX E

SYSTAT PROGRAM COMPUTER PRINTOUTS

```
   model oh1=constant+temp
 >est
    20 CASES DELETED DUE TO MISSING DATA
 DEP VAR      OH1       N       13  MULTIPLE R    757  SQUARED MULTIPLE R    574
 ADJUSTED SQUARED MULTIPLE R    535    STANDARD ERROR OF ESTIMATE        39 568
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT          -10 494       47 087        0 000            -0 223    0 828
    TEMP             2 719        0 707        0 757   100E+01   3 846    0 003
                              ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION      23157 581     1    23157 581      14 792       0 003
    RESIDUAL      17221 496    11     1565 591
DDDD
```

```
)
)
)
)
)
)
>MODEL OH4=CONSTANT+TEMP
>EST
   22 CASES DELETED DUE TO MISSING DATA
DEP VAR      OH4      N      11  MULTIPLE R    392  SQUARED MULTIPLE R    154
ADJUSTED SQUARED MULTIPLE R    060    STANDARD ERROR OF ESTIMATE        52 454
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
CONSTANT         102 135       83 146        0 000              1 228    0 250
   TEMP            1 517        1 186        0 392   100E+01    1 279    0 233
Press ENTER (-' or RETURN
                            ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION       4501 669     1     4501 669       1 636       0 233
   RESIDUAL      24763 058     9     2751 451
////////////////////////////////////////////////////////////////////////////////
>MODEL P4=CONSTANT+TEMP
>EST
    3 CASES DELETED DUE TO MISSING DATA
DEP VAR       P4      N      30  MULTIPLE R    721  SQUARED MULTIPLE R    520
ADJUSTED SQUARED MULTIPLE R    503    STANDARD ERROR OF ESTIMATE        43 527
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
CONSTANT        -100 388       50 728        0 000             -1 979    0 058
   TEMP            3 589        0 652        0 721   100E+01    5 506    0 000
Press ENTER (-' or RETURN
                            ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION      57433 717     1    57433 717      30 315       0 000
   RESIDUAL      53047 749    28     1894 562
////////////////////////////////////////////////////////////////////////////////
>MODEL OH1=CONSTANT+RH
>
```

```
 MODEL OH1=CONSTANT+RH
)EST
   20 CASES DELETED DUE TO MISSING DATA
DEP VAR      OH1      N       13  MULTIPLE R    284  SQUARED MULTIPLE R    081
ADJUSTED SQUARED MULTIPLE R    000    STANDARD ERROR OF ESTIMATE        58 097
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
CONSTANT          89 734       78 977        0 000              1 136    0 280
      RH           1 537        1 566        0 284   100E+01    0 981    0.347
                            ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION      3251 184     1     3251 184       0 963       0.347
   RESIDUAL     37127 893    11     3375 263
DDDD
```

```
Press ENTER <-' or RETURN
 )
 )
 )
 )
 )
 )
 )MODEL OH4=CONSTANT+RH
 )EST
    22 CASES DELETED DUE TO MISSING DATA
 DEP VAR:      OH4        N       11  MULTIPLE R   .199  SQUARED MULTIPLE R     040
 ADJUSTED SQUARED MULTIPLE R:    000    STANDARD ERROR OF ESTIMATE         55.881
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT          160 341       77.633        0 000  .          2.065    0.069
       RH            0 933        1 530        0.199  .100E+01   0.610    0 557
                             ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION       1160 796     1     1160 796       0 372       0.557
   RESIDUAL      28103 931     9     3122 659
Press ENTER <-' or RETURN
 DDDD
```

```
)
)
)
)
)
)
)
)MODEL OH1=CONSTANT+BP
)EST
   20 CASES DELETED DUE TO MISSING DATA
Press ENTER <-' or RETURN
 DEP VAR:     OH1      N:      13  MULTIPLE R.   279  SQUARED MULTIPLE R.  .078
 ADJUSTED SQUARED MULTIPLE R:  .000    STANDARD ERROR OF ESTIMATE.       58.181
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT        2422 561     2341 963        0.000             1 034    0.323
       BP          -2.226        2.310       -0 279   100E+01  -0 964    0.356
                            ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       3143 866     1     3143.866       0.929      0.356
    RESIDUAL      37235.211    11     3385 019
DDDD
```

```
 odel P2=CONSTANT+BP
>EST
    3 CASES DELETED DUE TO MISSING DATA.
Press ENTER <-' or RETURN
 DEP VAR       P2      N.      30  MULTIPLE R   .232  SQUARED MULTIPLE R    054
 ADJUSTED SQUARED MULTIPLE R    020    STANDARD EPROR OF ESTIMATE.       63.110
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT         2543 240     1860 573        0 000             1.367    0.183
       BP          -2.326        1.842       -0.232   100E+01   -1.263    0.217
                             ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       6349 638     1     6349 638       1.594       0.217
    RESIDUAL     111520 229    28     3982 865
DDDD
```

```
>MODEL OH1=CONSTANT+WIND
>EST
   20 CASES DELETED DUE TO MISSING DATA
Press ENTER <-' or RETURN
 DEP VAR:     OH1      N.      13  MULTIPLE R.   389  SQUARED MULTIPLE R.  .151
 ADJUSTED SQUARED MULTIPLE R:  .074    STANDARD ERROR OF ESTIMATE.       55.822
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT         137 204       25 533        0.000              5.374    0.000
    WIND            1 847        1 320        0.389   100E+01    1.399    0.189
                              ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION       6101 419     1     6101 419       1.958       0.189
   RESIDUAL      34277 658    11     3116 151
DDDD
```

```
Press ENTER <-' or RETURN
>MODEL OH4=CONSTANT+WIND
>EST
   22 CASES DELETED DUE TO MISSING DATA
DEP VAR.      OH4       N       11  MULTIPLE R    516  SQUARED MULTIPLE R.   266
ADJUSTED SQUARED MULTIPLE R.   184    STANDARD ERROR OF ESTIMATE:       48 860
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)
CONSTANT          168 149       25 874        0 000              6.499    0 000
    WIND            2 235        1 238        0 516   100E+01    1.805    0.105
                              ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION       7778 920     1     7778 920       3.258       0.105
   RESIDUAL      21485 808     9     2387 312
DDDD
```

```
>
>
>
>

>MODEL OH1=CONSTANT+ST1
>EST
   20 CASES DELETED DUE TO MISSING DATA
DEP VAR      OH1      N       13  MULTIPLE R·   791  SQUARED MULTIPLE R·   626
ADJUSTED SQUARED MULTIPLE R    592    STANDARD ERROR OF ESTIMATE        37.062
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)
CONSTANT        -134 973       70 832        0 000            -1.906    0.083
     ST1           5.030        1.173        0.791   100E+01   4 289    0.001
Press ENTER <-' or RETURN
                            ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION      25269 311     1    25269 311      18 396       0 001
   RESIDUAL      15109 766    11     1373 615
DDDD
```

```
>MODEL OH4=CONSTANT+ST4
>EST
   22 CASES DELETED DUE TO MISSING DATA
Press ENTER <-' or RETURN
 DEP VAR.     OH4       N       11  MULTIPLE R    610  SQUARED MULTIPLE R.  .372
 ADJUSTED SQUARED MULTIPLE R.   302    STANDARD ERROR OF ESTIMATE:       45.197
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT         -22.254      100.073        0.000            -0.222    0.829
      ST4           3.804        1 648        0 610   100E+01   2 308    0 046
                             ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION      10879 834     1    10879 834       5 326       0.046
    RESIDUAL      18384 893     9     2042 7aa
DDDD
```

```
Press ENTER ...
 ,
 ,
 ,
 ,
 ;
 >MODEL OH1=CONSTANT+SM1
 >EST
    21 CASES DELETED DUE TO MISSING DATA.
 DEP VAR      OH1       N       12  MULTIPLE R    010  SQUARED MULTIPLE R.   000
 ADJUSTED SQUARED MULTIPLE R.   000    STANDARD ERROR OF ESTIMATE        57.887
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT          181 238      296.723        0.000              0.611    0.555
      SM1           -0.663       21.864       -0.010   100E+01  -0.030    0 976
                             ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION          3 085     1        3 085       0 001       0.976
    RESIDUAL      33509 165    10     3350.917
Press ENTER <-  or RETURN
 DDDD
```

```
 /
Press ENTER <-  or RETURN

 /
 \
 >MODEL OH4=CONSTANT+SM4
 /EST
    22 CASES DELETED DUE TO MISSING DATA
 DEP VAR      OH4       N       11  MULTIPLE R    22a  SQUARED MULTIPLE R    051
 ADJUSTED SQUARED MULTIPLE R    000    STANDARD ERROR OF ESTIMATE        55 554
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT          324 525      170 679        0.000              1 901    0.090
     SM4            -7.532       10 844       -0 226   100E+01   -0 695    0 505
                           ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       1488 947     1     1488 947       0 482      0 505
    RESIDUAL      27775 780     9     308a 198
 DDDD
```

```
MODEL OH1=CONSTANT+DTF1
 >EST
    20 CASES DELETED DUE TO MISSING DATA
Press ENTER <-' or RETURN
 DEP VAR      OH1       N       13  MULTIPLE R    013  SQUARED MULTIPLE R    000
 ADJUSTED SQUARED MULTIPLE R    000    STANDARD ERROR OF ESTIMATE       60 582
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT         169 130       83 237        0 000              2 032    0 067
    DTF1           -2 108       48 906       -0 013   100E+01   -0 043    0 966
                             ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION          6 822     1        6 822       0 002      0 966
    RESIDUAL      40372 255    11     3670 205
DDDD
```

```
/MODEL OH4=CONSTANT+DTF4
 EST
   22 CASES DELETED DUE TO MISSING DATA
DEP VAR      OH4      N.      11  MULTIPLE R    063  SQUARED MULTIPLE R    004
ADJUSTED SQUARED MULTIPLE R    000    STANDARD ERROR OF ESTIMATE        56 911
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
CONSTANT          219 075       68 573        0 000             3 195    0 011
    DTF4           -7 414       39 237       -0 063   100E+01   -0 189    0 854
Press ENTER '-' or RETURN
                            ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE      F-RATIO       P
 REGRESSION        115 338     1       115 338       0 036       0 854
   RESIDUAL      29149 369     9      3238 819
DDDD
```

```
>MODEL OH1=CONSTANT+TEMP+RH+BP+WIND+DTF1+ST1+SM1
>EST
   21 CASES DELETED DUE TO MISSING DATA
Press ENTER <-' or RETURN
 DEP VAR      OH1      N.      12  MULTIPLE R    936  SQUARED MULTIPLE R.   877
 ADJUSTED SQUARED MULTIPLE R    660    STANDARD ERROR OF ESTIMATE        32 164
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)
 CONSTANT       -5064 346    2094 813       0 000             -2 418    0.073
    TEMP           1.747       1 449       0 493 0 1849195    1 206    0 294
      RH          -0 916       1 250      -0 185 0 4856264   -0 733    0 504
      BP           4 575       2 042       0.614 0 4102081    2.240    0.089
    WIND           1.736       1 207       0 390 0.4189155    1.438    0 224
    DTF1         -10 308      35 226      -0 068 0 5677253   -0 293    0.784
     ST1           4 534       2 212       0 757 0 2265528    2.050    0.110
     SM1          18 093      13.607       0 262 0 7970460    1 330    0 254
                          ANALYSIS OF VARIANCE
  SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION     29374 281     7     4196 326       4 056      0.097
   RESIDUAL      4137 989     4     1034 492
DDDD
```

```
\
\
Press ENTER <-  or RETURN
/
>
/
>

\
/
/MODEL OH2=CONSTANT+TEMP+RH+BP+WIND+DTF2
/MODEL OH2=CONSTANT+TEMP+RH+BP+WIND+DTF2+ST2+SM2
>EST
   21 CASES DELETED DUE TO MISSING DATA
 DEP VAR      OH2       N.       12  MULTIPLE R    922  SQUARED MULTIPLE P    851
Press ENTER <-  or RETURN
 ADJUSTED SQUARED MULTIPLE R    590    STANDARD ERROR OF ESTIMATE        58.557
   VARIABLE    COEFFICIENT    STD ERROR      STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT         1092 340     3820 558         0 000              0.286    0.789
    TEMP             0 259        2 779         0 044 0.1a65682   0 093    0 930
      RH            -1 484        2 278        -0 131 0 484a754  -0 a51    0 550
      BP            -1 a01        3 7a6        -0 130 0.3995141  -0 425    0.693
    WIND            -0 538        2 160        -0 073 0 4337379  -0 249    0 816
    DTF2           112 526      110 797         0 246 0 6378834   1.016    0 367
     ST2             8 708        3 883         0 889 0 2375465   2 243    0.088
     SM2             7 793       19 144         0 085 0 8a57947   0 407    0 705
                          ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE      F-RATIO       P
 REGRESSION      78171 139     7    11167 306        3 257      0.135
   RESIDUAL      13715 778     4     3428 945
DDDD
```

```
/
>MODEL OH4=CONSTANT+TEMP+RH+BP+WIND+DTF4+ST4+SM4
/EST
   22 CASES DELETED DUE TO MISSING DATA
Press ENTER (-' or RETURN
 DEP VAR:     OH4      N.      11  MULTIPLE R    923  SQUARED MULTIPLE R.    852
 ADJUSTED SQUARED MULTIPLE R.   507    STANDARD ERROR OF EST'MATE        37 968
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT          350 693    299' 494       0 000               0 117    0 914
    TEMP            -3 221       2 149      -0.833 0 1595554   -1.498    0.231
      RH            -0 432       1.428      -0 092 0.5295265   -0 303    0 782
      BP            -0 281       3 043      -0 038 0 2979153   -0 092    0 932
    WIND             2.816       1.668       0 650 0.3324759    1.688    0.190
    DTF4             4 676      40 970       0 040 0 4091892    0 114    0.916
     ST4             7 986       3 137       1 280 0 1948261    2 546    0.084
     SM4            -9 770       9 733      -0.293 0.5798070   -1.004    0.389
                             ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION      24940 041     7     3562 863       2 472      0.246
   RES'DUAL       4324 686     3     1441.562
DDDD
```

```
 NEW
WORKSPACE CLEAR FOR CREATING NEW DATASET
>USE DIURNAL
SYSTAT FILE VARIABLES AVAILABLE TO YOU ARE:
     TIME          TEMP           RH            BP          WIND
     SVP1          SVP2          SVP4
>CASELIST
>RUN
                   TIME          TEMP          RH          BP          WIND
                   SVP1          SVP2         SVP4
Press ENTER <-' or RETURN
  CASE     1        19.500        87 000       66.000     1009.000      2.000
  CASE     1       206.000       214.000      212.000
  CASE     2        21.500        81.000       82.000     1009.000      2.000
  CASE     2       213 000       227.000      215.000
  CASE     3         0.000        76.000       91.000     1011.000      2.000
  CASE     3       210.000       224.000      213.000
  CASE     4         2.500        74.000       98.000     1014.000      2.000
  CASE     4       208 000       228.000      215.000
  CASE     5         4 250        72.000       99.000     1015.000      2.000
  CASE     5       206.000       226 000      214.000
  CASE     6        11.000        83 000       62.000     1010.000      5.000
  CASE     6       208.000       223 000      217.000
  CASE     7        12.300        88.000       57.000     1009.000      7.000
  CASE     7       207.000       232.000      227.000
  CASE     8        15.000        93.000       52.000     1004.000     12.000
  CASE     8       214.000       244.000      213.000
  CASE     9        16.300        94.000       51.000     1002.000     12.000
  CASE     9       218 000       233 000      217.000
  CASE    10        17.800        92.000       54.000     1002.000     12.000
  CASE    10       221 000       239.000      215.000
  CASE    11        19.500        90.000       62.000     1004.000      7.000
  CASE    11       220.000       229.000      210.000
  CASE    12        20.500        86.000       73.000     1007.000      6.000
  CASE    12       220 000       239 000      216.000
Press ENTER <-' or RETURN
  CASE    13        22.800        82.000       84.000     1010 000      7.000
  CASE    13       209.000       224.000      209.000
  CASE    14         6.250        69 000       97.000     1013.000      8.000
  CASE    14       203 000       232 000      213 000
  CASE    15         8.750        72.000       96 000     1015.000     15.000
  CASE    15       201.000       240 000      223.000
  CASE    16        12.500        87.000       67.000     1007.000     20.000
  CASE    16       209.000       240.000      205.000
    16 CASES AND    8 VARIABLES PROCESSED
NO SYSTAT FILE CREATED.

>MODEL SVP1=CONSTANT+TEMP
$$$ERROR$$$
ABOUT HERE SYSTAT EXPECTS A SYSTAT COMMAND
MODEL SVP1=CONSTANT+TEMP
    ^
>
```

```
 MODEL SVP1=CONSTANT+TEMP
Press ENTER <-' or RETURN
 >EST
 DEP VAR.    SVP1      N.      16  MULTIPLE R   .723  SQUARED MULTIPLE R:  .522
 ADJUSTED SQUARED MULTIPLE R    488    STANDARD ERROR OF ESTIMATE.        4.452
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT          164 958      11 780        0.000  .          14.004    0.000
    TEMP             0.553       0 142        0.723  .100E+01    3.910    0.002
                              ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       302 999     1      302 999      15.290       0.002
    RESIDUAL       277.439    14       19 817
DDDD
```

```
>MODEL SVP1=CONSTANT+RH
>EST
Press ENTER '-' or RETURN
 DEP VAR.    SVP1       N:      16  MULTIPLE R.   .605  SQUARED MULTIPLE R:  .366
 ADJUSTED SQUARED MULTIPLE R:   .321    STANDARD ERROR OF ESTIMATE:        5.126
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT          226.529        5.673        0.000 .          39.933    0.000
       RH           -0.211        0.074       -0.605 .100E+01   -2.844    0.013
                             ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       212.549     1       212.549       8.089      0.013
   RESIDUAL        367.889    14        26.278
DDDD
```

```
>MODEL SVP1=CONSTANT+BP
>ESRT
Press ENTER <-' or RETURN
 DEP VAR.    SVP1       N.       16  MULTIPLE R.   846  SQUARED MULTIPLE R:  .715
 ADJUSTED SQUARED MULTIPLE R    695    STANDARD ERROR OF ESTIMATE.          3.435
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT        1451 668      209 206        0 000  .          6.939    0.000
       BP          -1.230        0 207       -0.846   100E+01  -5.931    0.000
                            ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       415 207     1       415.207      35.181      0.000
    RESIDUAL       165 230    14        11.802
DDDD
```

```
 MODEL SVP1=CONSTANT+WIND
>EST
DEP VAR:    SVP1      N:      16  MULTIPLE R:  .089  SQUARED MULTIPLE R:  .008
ADJUSTED SQUARED MULTIPLE R:  .000    STANDARD ERROR OF ESTIMATE:        6.413
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
CONSTANT         210.034        2 827        0.000  .         74.297    0.000
    WIND           0.103        0.308        0.089  .100E+01   0.334    0.743
Press ENTER (-' or RETURN

                           ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION         4 602     1        4 a02       0.112       0.743
   RESIDUAL       575 836    14       41.131
DDDD
```

```
 MODEL SVP1=CONSTANT+TEMP+RH+BP+WIND
>EST
DEP VAR.    SVP1      N:      16  MULTIPLE R:  .934  SQUARED MULTIPLE R:  .872
ADJUSTED SQUARED MULTIPLE R.   826    STANDARD ERROR OF ESTIMATE.        2.598
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
CONSTANT         2254.805      483.833        0.000             4.660    0.001
    TEMP            0.190        0.390        0 249 0.0448742   0.488    0.635
      RH            0 279        0.136        0.799 0.0763778   2.049    0.065
      BP           -2.060        0 456       -1.417 0.1184418  -4.521    0.001
    WIND           -0 285        0.137       -0 246 0 8253196  -2.076    0.062
Press ENTER <-' or RETURN

                          ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES   DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION        506.191    4      126 548      18.749      0.000
   RESIDUAL         74.246   11        6.750
DDDD
```

```
 MODEL SVP1=CONSTANT+TEMP+RH+BP
>EST
DEP VAR.    SVP1      N:      16  MULTIPLE R.   907  SQUARED MULTIPLE R:  .822
ADJUSTED SQUARED MULTIPLE R   .777    STANDARD ERROR OF ESTIMATE.        2.935
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
CONSTANT        2033.282      533 065        0.000  .          3.814    0.002
    TEMP           0.328        0 434        0.428 0 0462114  0.756    0.464
      RH           0.327        0 151        0 939 0 0786979  2.162    0.052
      BP          -1.858        0 503       -1.277 0.1241314 -3.695    0.003
Press ENTER  -' or RETURN

                              ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE      F-RATIO       P
 REGRESSION       477.094     3      159 031       18.466       0.000
   RESIDUAL       103.344    12        8 612
DDDD
```

```
 MODEL SVP1=CONSTANT+TEMP+BP
>EST
DEP VAR.    SVP1      N:      16  MULTIPLE R:  .868  SQUARED MULTIPLE R:  .753
ADJUSTED SQUARED MULTIPLE R.   715    STANDARD ERROR OF ESTIMATE.        3.323
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
CONSTANT        2234.136      594 443        0 000  .          3.758    0.002
    TEMP          -0.417        0 298       -0.545 0 1255046  -1.400    0.185
      BP          -1.971        0.566       -1 356 0.1255046  -3.481    0.004
Press ENTER <-' or RETURN

                                ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION       436.853     2      218 427      19.776       0.000
   RESIDUAL       143.584    13       11.045
DDDD
```

```
>MODEL SVP1=CONSTANT+TEMP+WIND
>EST
DEP VAR:    SVP1      N:      16  MULTIPLE R:   742  SQUARED MULTIPLE R:  .550
ADJUSTED SQUARED MULTIPLE R    481    STANDARD ERROR OF ESTIMATE:          4.483
  VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)
CONSTANT          162 675      12.133        0.000  .          13.408    0.000
    TEMP            0.600       0 152        0.783 0.8840839   3.956    0.002
    WIND           -0.205       0 229       -0.178 0 8840839  -0.897    0.386
Press ENTER <-' or RETURN

                            ANALYSIS OF VARIANCE
   SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
 REGRESSION        319.171     2      159 585       7.941      0.006
   RESIDUAL        261.267    13       20.097
DDDD
```

```
 MODEL SVP1=CONSTANT+BP+WIND
>EST
Press ENTER <-' or RETURN
 DEP VAR     SVP1      N:      16  MULTIPLE R.  .883  SQUARED MULTIPLE R:  .780
 ADJUSTED SQUARED MULTIPLE R:  .746    STANDARD ERROR OF ESTIMATE:        3.133
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT        1609.209     207 027        0 000  .          7.773    0.000
       BP          -1.384       0.205       -0.952 0 8529953  -6.759    0.000
     WIND          -0.319       0.163       -0.276 0.8529953  -1.959    0.072
                              ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       452.662     2       226.431      23.074      0.000
    RESIDUAL       127 575    13         9.813
DDDD
```

```
 MODEL SVP1=CONSTANT+RH+BP
>EST
Press ENTER <-' or RETURN
 DEP VAR.    SVP1       N.      16  MULTIPLE R.  .902  SQUARED MULTIPLE R:  .813
 ADJUSTED SQUARED MULTIPLE R:   785    STANDARD ERROR OF ESTIMATE:        2.886
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE    T   P(2 TAIL)
 CONSTANT         2315.587     374 175        0.000  .          6.189    0.000
       RH            0 236       0.090        0.678 0.2137339   2.615    0.021
       BP           -2.104       0 377       -1 447 0.2137339  -5.583    0.000
                             ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       472 170     2      23a 085      28.347       0.000
    RESIDUAL       108.268    13       8.328
DDDD
```

```
 MODEL SVP1=CONSTANT+RH+WIND
>EST
Press ENTER <-' or RETURN
 DEP VAR:    SVP1      N:      16  MULTIPLE R:  .622  SQUARED MULTIPLE R:  .386
 ADJUSTED SQUARED MULTIPLE R:  .292    STANDARD ERROR OF ESTIMATE.        5.234
   VARIABLE    COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T   P(2 TAIL)
 CONSTANT         229 313        7.189        0.000  .          31.897    0.000
       RH          -0.231        0.081       -0.661 0.8663064  -2.831    0.014
     WIND          -0.177        0 270       -0.153 0.8663064  -0.654    0.525
                              ANALYSIS OF VARIANCE
    SOURCE   SUM-OF-SQUARES    DF  MEAN-SQUARE     F-RATIO       P
  REGRESSION       224.262     2      112.131       4.093       0.042
    RESIDUAL       356.175    13       27.398
DDDD
```

VITA 2

Timothy A. Bent

Candidate for the Degree of

Master of Science

Thesis: MEASUREMENT OF VOLATILE ORGANIC VAPORS IN SOILS AS A TECHNIQUE FOR CHARACTERIZING GASOLINE CONTAMINATION IN GROUND WATER AT A BULK FUEL LOADING FACILITY; INCLUDING AN ANALYSIS OF THE EFFECTS OF ENVIRONMENTAL VARIABLES

Major Field: Geology

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Personal Data: Born in Ashtabula, Ohio, May 8, 1957, the son of Irene S. Oldham and Henry F. Bent, Jr.

Education: Graduated from Harbor High School, Ashtabula, Ohio, in June, 1975; graduated with Dual Bachelor of Science Degree in Geology and Conservation from Kent State University in August, 1981; completed requirements for the Master of Science degree in Geology at Oklahoma State University in December, 1991.

Professional Experience: Well-site consultant for Technical Drilling Services, Oklahoma City, Oklahoma, 1981 to 1983. Well-site consultant for Pinco Drilling Services, Oklahoma City, Oklahoma, 1983 to 1985. Geological Manager, RAMPCO, Oklahoma City, Oklahoma, 1985 to 1988. Consultant Hydrogeologist, under contract with Kerr-McGee Corporation, Oklahoma City, Oklahoma, 1988 to July, 1991. Currently Senior Hydrogeologist at McLaren/Hart, Cleveland, Ohio.